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(54) PROCEDE ET APPAREIL POUR LA RESERVATION DE RESSOURCES D'UNE OU PLUSIEURS VOIES DE COMMUNICATION A ACCES MULTIPLES

(54) METHOD AND APPARATUS FOR RESERVING RESOURCES OF ONE OR MORE MULTIPLE ACCESS COMMUNICATION CHANNELS

(57)

A method and system are disclosed for enabling point-to-point and multicast communication in a multiple access network using three types of communication channels, namely one or more upstream payload channels (f2), one or more upstream control channels (f3) and one or more downstream channels (f1). Each channel (f1, f2, f3) illustratively is divided into slots or mini-slots. Each upstream payload channel (f2) is assigned for carrying upstream directed payload bitstreams from stations (150) to a central controller (112). The central controller (112) has an independent receiver (254, 255) for each upstream channel (f2, f3) for simultaneous reception of control and payload bitstreams. Each station (150) has at least one frequency agile programmable transmitter (390), or separate upstream control and payload channel transmitters (178, 184), respectively, for simultaneous transmission of control and payload bitstreams. Each upstream control channel (f3) is assigned for carrying upstream directed control bitstreams, such as reservation request bitstreams requesting reservation of time slots of the upstream payload channel (f2), from the stations (150) to the central controller (112) . At least one downstream channel (f1) is assigned for carrying at least downstream directed control bitstreams, such as bitstreams containing network configuration acknowledgements, collision, status of reservation request, and also containing indications of assigned slots in the upstream payload channel (f2), from the central controller (112) to the stations (150) . The downstream channel (f1) may also illustratively carry payload bitstreams.

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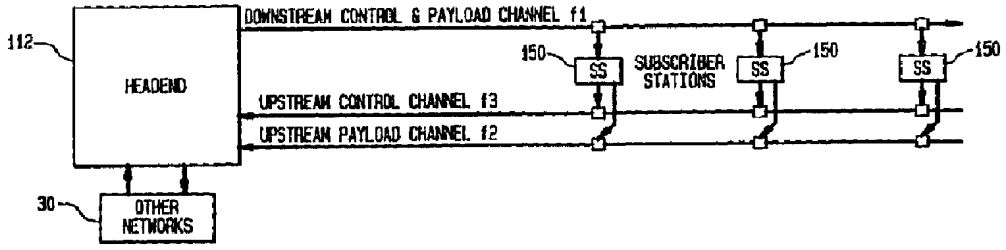
(54) **PROCEDE ET APPAREIL POUR LA RESERVATION DE RESSOURCES D'UNE OU PLUSIEURS VOIES DE COMMUNICATION A ACCES MULTIPLES**

(54) **METHOD AND APPARATUS FOR RESERVING RESOURCES OF ONE OR MORE MULTIPLE ACCESS COMMUNICATION CHANNELS**




(57) L'invention concerne un procédé et un système permettant une communication point à point ou à multidestination dans un réseau à accès multiples, dans lesquels trois types de voies de communication sont utilisées, à savoir une ou plusieurs voies de données utiles d'amont (f2), une ou plusieurs voies de commande d'amont (f3) et une ou plusieurs voies d'aval (f1). Chaque voie est divisée en créneaux ou en mini-créneaux. Chaque voie de données utiles d'amont (f2) est désignée pour transporter des trains binaires de données utiles vers l'amont de postes (150) à un contrôleur central (112). Le contrôleur central (112) comporte un récepteur indépendant (254, 255) pour chaque voie d'amont (f2, f3), conçu pour la réception simultanée des trains binaires de données de commande et de données utiles. Chaque poste (150) comprend au moins un émetteur programmable à agilité de fréquence (390), ou des émetteurs séparés (178, 184) sur voies de données utiles et de données de commande d'amont, pour, respectivement, la transmission simultanée de trains binaires de commande et de données utiles. Chaque voie d'amont de données de commande (f3) est désignée pour transporter des trains binaires de données de commande dirigés vers l'amont, tels que des trains binaires de

(57) A method and system are disclosed for enabling point-to-point and multicast communication in a multiple access network using three types of communication channels, namely one or more upstream payload channels (f2), one or more upstream control channels (f3) and one or more downstream channels (f1). Each channel (f1, f2, f3) illustratively is divided into slots or mini-slots. Each upstream payload channel (f2) is assigned for carrying upstream directed payload bitstreams from stations (150) to a central controller (112). The central controller (112) has an independent receiver (254, 255) for each upstream channel (f2, f3) for simultaneous reception of control and payload bitstreams. Each station (150) has at least one frequency agile programmable transmitter (390), or separate upstream control and payload channel transmitters (178, 184), respectively, for simultaneous transmission of control and payload bitstreams. Each upstream control channel (f3) is assigned for carrying upstream directed control bitstreams, such as reservation request bitstreams requesting reservation of time slots of the upstream payload channel (f2), from the stations (150) to the central controller (112). At least one downstream channel (f1) is assigned for carrying at least downstream

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demande de réservation demandant la réservation de créneaux temporels de la voie d'amont de données utiles (f2), des postes (150) au contrôleur central (112). Au moins une voie d'aval (f1) est désignée pour transporter au moins des trains binaires de commande dirigés vers l'aval, tels que des trains binaires contenant des accusés réception de configuration de réseau, l'état de collision d'une demande de réservation et des indications sur les intervalles attribués dans la voie de données utiles d'amont (f2), du contrôleur central (112) aux postes. La voie d'aval (f1) peut également transporter des trains binaires de données utiles.

directed control bitstreams, such as bitstreams containing network configuration acknowledgements, collision, status of reservation request, and also containing indications of assigned slots in the upstream payload channel (f2), from the central controller (112) to the stations (150). The downstream channel (f1) may also illustratively carry payload bitstreams.

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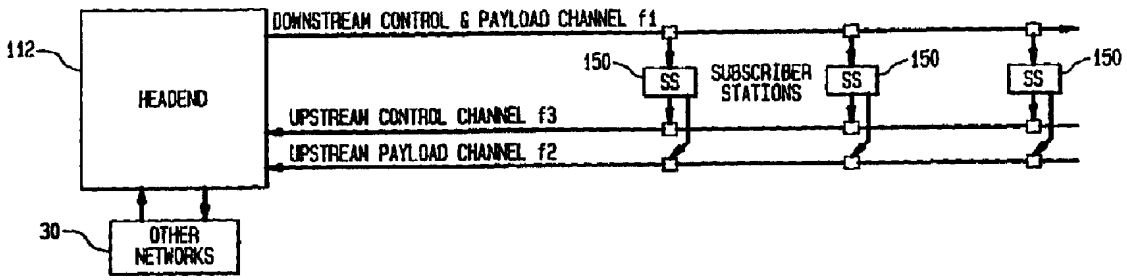



(57) Abstract

A method and system are disclosed for enabling point–to–point and multicast communication in a multiple access network using three types of communication channels, namely one or more upstream payload channels (f2), one or more upstream control channels (f3) and one or more downstream channels (f1). Each channel (f1, f2, f3) illustratively is divided into slots or mini–slots. Each upstream payload channel (f2) is assigned for carrying upstream directed payload bitstreams from stations (150) to a central controller (112). The central controller (112) has an independent receiver (254, 255) for each upstream channel (f2, f3) for simultaneous reception of control and payload bitstreams. Each station (150) has at least one frequency agile programmable transmitter (390), or separate upstream control and payload channel transmitters (178, 184), respectively, for simultaneous transmission of control and payload bitstreams. Each upstream control channel (f3) is assigned for carrying upstream directed control bitstreams, such as reservation request bitstreams requesting reservation of time slots of the upstream payload channel (f2), from the stations (150) to the central controller (112). At least one downstream channel (f1) is assigned for carrying at least downstream directed control bitstreams, such as bitstreams containing network configuration acknowledgements, collision, status of reservation request, and also containing indications of assigned slots in the upstream payload channel (f2), from the central controller (112) to the stations (150). The downstream channel (f1) may also illustratively carry payload bitstreams.

# METHOD AND APPARATUS FOR RESERVING RESOURCES OF ONE OR MORE MULTIPLE ACCESS COMMUNICATION CHANNELS

## Field of the Invention

The present invention relates to communication networks, such as hybrid fiber coaxial (HFC) cable networks, wireless communication networks, satellite networks, etc., in which multiple subscriber stations transmit messages on one or more unidirectional multiple access communication channels. In particular, the present invention relates to enabling each subscriber station to reserve a portion of one or more multiple access unidirectional communication channels for contention free access. This enables the cable network to be used for point-to-point and multicast communication in addition to conventional broadcast TV.

## Background of the Invention

It is desirable to provide ubiquitous, integrated high speed and high capacity digital communication services (such as video, data and voice) to homes, schools, governments, and businesses. One such network, the telephone network, could be upgraded to provide such services. However, the century-old copper telephone network, primarily designed for telephony, has a usable bandwidth of only about 1 MHZ. Therefore, it is quite difficult and expensive to provide multi-channel digital video, along with data and voice on the telephone network. On the other hand, the coaxial drop line of a cable network to each home has a high usable bandwidth of about 1 GHz,

providing ample speed and capacity to the integrated broadband services listed above, in addition to delivering traditional broadcast analog video programs. These traditional coaxial cable networks can be readily upgraded to bidirectional hybrid fiber-coaxial cable networks (HFC networks) to enable bidirectional high speed and high capacity communications. The HFC network is inherently a shared medium technology. Nevertheless, providing efficient, high speed, high capacity shared access to the upstream transmission has been a challenge to the communication industries.

FIG 1 shows a conventional bidirectional hybrid fiber coaxial (HFC) cable network 10 having a head end 12. The head end 12 has a head end controller 28 that can communicate with one or more other networks 30, such as the Internet and local area networks. Downstream directed signals are transmitted from, and upstream directed signals are received at, the head end controller 28 via a coaxial link 34 connected to a diplexer 32. The diplexer 32 splits the downstream directed signals from the other signal carried on the link 34 and outputs them to a laser transmitter 36. The laser transmitter 36 modulates the downstream directed signals onto an optical signal that is transmitted via a downstream optical fiber trunk 14. Likewise, upstream directed signals modulated on a signal carried via an upstream optical fiber trunk 14' may be demodulated at an optical receiver 38. The diplexer 32 combines such upstream directed signals with the other signals carried on the link 34 for receipt at the head end controller 28.

The upstream and downstream optical trunks 14, 14' connect the head end 12 to an optical node 16. The head end 12 and optical node 16 may be separated by up to about 80 kilometers. Like the head end 12, the optical node 16 has a laser transmitter 40, an optical receiver 42 and a diplexer 44. The laser transmitter 40 is for modulating upstream directed signals received via the diplexer 44 onto an optical signal for transmission on the upstream directed optical trunk 14'. The optical receiver 42 is for demodulating downstream directed signals from the optical signal carried on downstream optical trunk 14 and transferring the demodulated downstream directed signal to the diplexer 44.

The diplexer 44 outputs onto coaxial trunk 18 the downstream directed signals that are demodulated by the optical receiver. Likewise, the diplexer 44 receives from the coaxial trunk 18 upstream directed signals for modulation by the laser transmitter 40. The individual links of the coaxial trunk 18 are interconnected by bidirectional amplifiers 20 and taps 22. Taps 22 are also provided for connecting coaxial drop lines 22 to the coaxial trunk 18. The coaxial drop lines 22 connect the subscriber locations 26 to the coaxial trunk 18 for upstream and downstream directed communication.

The optical trunks 14, 14', coaxial trunks 18, taps 20 and coaxial drop lines 22 define a shared communications medium over which communicated signals are transmitted or received by all connected network devices, such as subscriber stations at the subscriber locations 26 and the head end 12. The cable network 10 is specifically designed to deliver information in the downstream direction from the head end 12 to the

subscriber locations 26. For downstream directed communication, frequency division multiplexed communication channels are defined which have mutually unique carrier frequencies and non-overlapping bands (6 MHZ bands in North America and other NTSC cable TV systems, 8 MHZ bands in Europe and other PAL and SECAM cable TV systems) in the band from 54 MHZ up to the upper cut-off frequency of the coaxial trunks 18 and drop lines 22 (typically, 500-750 MHZ). This is also known as sub-split cable network. Each 6 MHZ downstream channel can carry either traditional analog NTSC composite video signals or digitally encoded data appropriately modulated by a RF carrier. Each traditional broadcast video programs are each transmitted in a separate communication channel by modulating an NTSC signal onto a predetermined carrier signal having an assigned carrier frequency and transmitting the signal from the head end controller 28.

Although the cable network 10 has a large amount of bandwidth, the cable network 10 presents certain challenges for providing high speed and high capacity upstream transmission from a large number (typically a few hundred) of subscriber locations 26. Most notably, the subscriber locations 26 may be distributed over a large geographic area. The signal path (i.e., sum of the lengths of the coaxial drop lines 22, coaxial trunk links 18 and optical trunk links 14) between individual subscriber locations 26 or subscriber locations 26 and the cable head end 12 can be on the order of tens of kilometers. Such long signal paths introduce noticeable delays in the transmission of signals which tend to be about 5$\mu$s/kilometer.

Recognizing such challenges, several standard bodies and industry consortiums, such as IEEE 802.14, SCTE, MCNS and DAVIC have proposed similar communication schemes as follows. Two channels are defined for communication, namely, an upstream directed channel (UC) and a downstream directed channel (DC). Subscriber stations (SSs) 50 (FIG 2), such as cable modems, set top boxes or data terminals, at subscriber locations 26 can transmit on the upstream directed channel UC but can only receive on the downstream directed channel DC. The head end 12 can only receive on the upstream directed channel UC and only transmit on the downstream directed channel DC. In other words, the upstream channel UC is a multi-point to point channel whereas the downstream channel DC is a point to multi-point channel. These channels UC and DC are said to be multiple access channels, meaning that multiple network devices (SSs 50, head end 12, etc.) are permitted to access each channel UC or DC. As such, although the physical topology of the cable network 10 is a tree and branch configuration, the communication channels UC and DC may be illustrated as a logical bus network as shown in FIG 2.

Each channel UC and DC is assigned a different frequency band and center frequency, such as is shown in FIG 3. As shown, the upstream channel UC may be assigned a band in the 5-42 MHZ band not already used for control message communication. The downstream channel DC may be assigned one of the unused 6 MHZ bands, i.e., not currently used for communicating traditional broadcast video programming. The DC channel is divided into time slots and the UC channel is divided time slots ("slots") and

mini-time slots ("mini-slots"). Point-to-point or multicast communication is achieved by reading packets from, or writing packets into, the slots and mini-slots in a time division multiplexing or time division multiple access fashion. (Herein, a "packet" is an organization of a bitstream into discrete units. A packet may include control or overhead information, typically located in a header section of the packet, and user message or user data information in a "payload" section of the packet. The term "payload" is used herein more generally to refer to a channel for carrying communicated data or messages.) In order to read a packet from a channel, the particular channel is tuned (the frequency band of that channel is filtered out of the signals carried on the shared medium), and a packet is demodulated from a respective slot or mini-slot time period of the carrier signal. Likewise, in writing a packet to a channel, a packet is modulated onto a carrier signal of that channel and the modulated carrier signal is transmitted at the appropriate slot or mini-slot time period of the carrier signal and combined with the other signals carried on the shared medium.

It should be noted that the cabling distance (i.e., signal path) between any two SSs 50 and the head end 12 or the mutual cabling distance between any two SSs 50 can widely vary in the cable network 10. As such, a wide disparity of propagation delays may be incurred by each signal transmitted to or from an SS 50 depending on its relative distance to the head end 12. Assuming that the SSs 50 are synchronized to a system clock at the head end 12 using a time-stamping technique (to be detailed later), a packet transmitted at "the same time" from different SSs 50 will arrive at

the head end 12 at different times. The difference can be on the order to tens of μsec. If not properly compensated, a large guard time must be inserted between each packet transmission, resulting in a very inefficient time division multiplexing (TDM) transmission in the upstream channels. To overcome this problem, the following procedure, which is generally known, will be described. Each SS 50 is polled and transmits a signal to the head end 12. The head end 12 records the propagation delay of each SS 50. The head end 12 then informs each SS 50 of how long a propagation delay is incurred by signals transmitted from that specific SS 50 to the head end 12. Each SS 50 is also informed of the maximum propagation delay of all SSs 50 in the cable network 10. Whenever a SS 50 decides to transmit a signal, the SS 50 determines the slot or mini-slot boundary at which it desires to write its packet. The SS 50 then delays its transmission from the slot or mini-slot boundary for a certain time period equal to the difference between the propagation delay of the transmitting SS 50 and the maximum propagation delay in the cable network 10. The net effect is that all signals received at the head end 12 "appear" to incur the same propagation delay as the SS 50 that incurs the maximum propagation delay.

Each SS 50 is assigned a unique identifier or address. Each packet written into each slot contains at least the address of the destination, i.e., the SS 50, which is the ultimate intended recipient of the packet. A SS 50 transmits information to another SS 50 or to the head end 12 by dividing the information into packets and writing the packets into allocated slots of the upstream channel UC. Such packets are broadcasted by the upstream

channel UC to the head end 12 which reads each packet from each time slot. The head end 12 examines the destination address in the header of the packet. The head end 12 writes the packet into an available slot of the downstream channel DC. The packets are broadcasted in the downstream channel DC and are read from the slots by each SS 50. Each SS 50 compares the destination address of the received packets to its assigned address or to the group (multicast) addresses assigned to the multicast groups to which the SS 50 has subscribed. If the addresses match, the packet is accepted. Otherwise, the packet is discarded.

As will be described in greater detail below, two types of packets are transmitted in the channels UC and DC, namely, "payload" packets and "control" packets. Payload packets carry user messages or user data to be communicated to a destination. Control packets carry control messages for allocating portions of the communication channels or other overhead control information. For reasons described below, SSs 50 write control packets into mini-slots of the upstream channel UC and write payload packets into slots of the upstream channel UC. The head end 12 writes payload and control packets into slots of the downstream channel DC. For example, each slot of the downstream channel DC accepts a frame which includes one payload packet and one control packet. This is possible because only the head end 12 writes control and payload packets into slots of the downstream channel DC.

Some manner must be provided to prevent each SS 50 from attempting to write packets into the same time slot of the upstream channel UC. To that end, a slot assignment-reservation protocol is implemented according to which each SS 50 may only write packets into slots that have been assigned to that SS 50. Each SS 50 can attempt to reserve slots (i.e., request an assignment of one or more slots) by writing a reservation request control packet into a mini-slot of the upstream channel UC allocated for receiving new reservation request packets. The reservation request control packet may indicate the address or identifier of the SS, the number or size of slots needed for the to-be-communicated payload packets, (conventionally, the slot length may be an integral number of mini-slot lengths and thus the number of slots needed may be expressed as the number of "mini-slot" lengths needed), the type of the communication for which slots are requested and an error check sequence (e.g., a cyclical redundancy check or CRC). The head end 12 receives the reservation request control packets from the mini-slots and responds by assigning one or more slots to each requesting SS 50. The head end 12 then writes control packets into slots of the downstream channel DC indicating which slots were assigned to each SS 50. Each SS 50 receives control packets that respond to its respective reservation request and then transmits its payload packets only in its assigned slots. Because SS's 50 only transmit payload packets in their assigned slots, no other SS 50 contends to simultaneously access the same slot. Contention is therefore localized to relatively small size reservation mini slots, and not the relatively lengthy payload packets. Consider that each slot

or mini-slot accessed by more than one SS 50 simultaneously (thereby resulting in a collision) is wasted. As such, the use of mini-slots enables the SSs 50 to obtain access to the larger slots in a fashion that conserves the bandwidth.

The payload packets are received at the head end 12. The head end 12 identifies each received payload packet destined to a SS 50 in the cable network 10, and writes each of the identified packets into an available slot of the downstream channel DC. Each SS 50 receives from the downstream channel the payload packets destined thereto.

Nevertheless, contention exists in accessing the mini-slots. Such contention is resolved using a feedback mechanism and a collision resolution algorithm (CRA). The head end 12 monitors each mini-slot and determines if a collision has occurred. If the head end 12 detects a collision, the head end 12 transmits a message via the downstream channel DC indicating in which slots a collision was detected. Each SS 50 that has attempted to transmit a reservation request packet monitors the messages transmitted in the downstream channel DC. If an SS 50 receives a message from the head end 12 indicating that a collision has occurred in the same mini-slot in which the SS 50 had previously attempted to write its reservation request packet, the SS 50 determines that its reservation request packet had collided with another transmission by another device and therefore was not received by the head end 12. In such a case, the SS 50 executes a CRA to determine whether and when to attempt to retransmit its reservation request packet. Several CRA's are known such as "ternary tree," and "P-persistent and

DQRAP." See P. Jacquet, P. Muhlethaler & P. Robert, *Asymptotic Average Access Delay Analysis: Adaptive P-Persistence Versus Tree Algorithm,* IEEE P802.14, Doc. no. IEEE 802.14-96/248 (1996), and U.S. Patent No. 5,390,181.

It is desirable to reduce contention to increase the utilization of the bandwidth in the upstream and downstream channels UC and DC and, at the same time, accommodate as large a number of SSs 50 as possible. Generally, this is achieved by increasing the ratio of mini-slots to payload slots in the upstream channel UC and decreasing the size of the mini-slots in the upstream channel UC. U.S. Patent Nos. 5,012, 469 and 5,390,181 describe different variations in the ratio and arrangement of mini-slots to payload slots in the upstream channel UC. The upstream spectrum 5-42 MHZ of a sub-split HFC cable network is susceptible to noises and interference that can limit the amount of spectrum available for reliable transmissions. The noises are, most notably, "ingress noise" and "impulse noise." Ingress noise occurs because the coaxial cabling of the trunks 18 and drop lines 22, with imperfect shielding due to corroded connectors, cracked sheath, etc., function as antennas. Different radio transmissions are picked up by the shared medium, such as citizen band (CB) radio broadcasts at around 24 MHZ, short wave radio transmissions at various points in the 5-42 MHZ band, etc., and contribute to ingress noise. Impulse noise, on the other hand, results from noise spikes that occur from other phenomenon such as lightning strikes of the coaxial cabling. The coaxial cabling of the trunks 18 may also carry an electrical power signal for supplying power to

the various devices (e.g., amplifiers 20) of the cable network. Power line arching through weak points of the cables and connectors also contribute to the impulse noise.

In order to reliably transmit control packets, such as reservation request packets, in mini-slots, a binary phase shift keying (BPSK) modulation technique or quaternary phase shift keying (QPSK) modulation technique is often used. On the other hand, to maximize the amount of data transmitted in payload packets, a high order quadrature amplitude modulation (QAM) technique such as 16-QAM, 64-QAM or even 256 QAM, with powerful forward error correction (FEC) is often used. However, spectral efficient modulation schemes, such as 16-QAM, 64-QAM and 256-QAM, require longer preambles for carrier recovery and burst synchronization and incur a much higher per burst overhead for mini-slots. That is, each SS 50 actually writes a frame into each mini-slot time period, including an inter-burst guard time period and a preamble, that precede the actual mini-slot control packet, such as is shown in FIG 4. (FIG 4 also shows the mini-slot packet structure as including an address or identifier, payload packet or communication type indicator, number of requested mini-slots field and CRC field.) The devices of the cable network 10 may use raised cosine filters. Such filters introduce a ringing into the channel. In addition, transmitters and receivers of the SSs 50 and head end 12 need a finite amount of time to turn on and off in order to read and write packets into specified slots. The purpose of the guard time period is to provide sufficient time for the ringing to dampen and to enable the transmitter or receiver circuitry of the SSs 50 and head end 12 to

turn on or off. Following the guard time period is a "burst" or combination of a preamble and modulated data. The purpose of the preamble is to enable a receiver to fine tune to the carrier frequency of the carrier signal on which the data is modulated and to align in phase to the carrier signal, prior to sampling the carrier signal and demodulating data from the carrier signal. This synchronization and alignment operation is referred to as "burst sync." Longer preambles are required when spectral efficient, higher order QAM schemes are used to ensure very fine tuning thereby ensuring highly accurate sampling and demodulation. The impact of such effects on mini-slot efficiency are more pronounced as the order of the QAM increases, as depicted in FIG 5. That is, a larger percentage of the time of the upstream channel UC is allocated to mini-slots as the order of the QAM increases.

To increase the utilization of the upstream channel UC, a technique of varying the time division pattern of the upstream channel UC into mini-slots and slots has also been proposed. This is illustrated in FIG 6. At the top of FIG 6, a fixed time division pattern of the upstream channel UC into slots and mini-slots is shown. The disadvantage of this technique is that much of the upstream channel UC capacity must be allocated to mini-slots to account for a typical worst case, or heavy load (numerous attempts to access mini-slots), scenario. In the alternative conventional technique, the ratio of mini-slots to slots can be dynamically varied by rearranging the pattern according to which the upstream channel is time divided into slots and mini-slots. This is depicted at the bottom of FIG 6. For example, when the load is anticipated to be light (few attempts to access mini-slots), the ratio of mini-

slots to slots is reduced. When the load is anticipated to be heavy, the ratio of mini-slots to slots is increased. However, this technique has the following disadvantages:

(1) It is complex to implement.

(2) It is difficult and imprecise to predict the load based on past history, thereby risking a potential stability problem.

(3) It imposes additional constraints on the mini-slot, such as requiring that slots lengths be equal to an integral multiple of mini-slot lengths, further reducing the utilization of the upstream channel UC for payload data.

Although prior art (including those proposed in the emerging standards, such as IEEE 802.14, SCTE, MCNS and DAVIC may include multiple upstream channel support, each upstream channel is statically assigned to the station and each channel is still required to support both the control and payload bitstreams. Such a network still exhibits the inefficiency, high network latency and large delay of a single upstream channel.

U.S. Patent No. 5,278,833 describes a wireless network including a base station and "communication units," such as cellular or cordless phones. This patent describes the circuitry and communication formats in detail. Therefore, only certain details of this wireless communication system are repeated herein. A frequency division multiplexing technique is used to form two channels, namely, an upstream channel having a first band, and a downstream channel, having a second, non-overlapping band. As above, the upstream channel is used for transmitting information from the

communication units to the base station and the downstream channel is for communicating information from the base station to the communication units.

Like the cable network 10, a time division multiplexing technique is used to divide each of the upstream and downstream channels into time slots. Each of the time slots may be assigned by the base station for communication between a selected communication unit and the base station. Unlike the cable network 10, the upstream channel is divided only into uniform sized time slots. However, whenever a time slot of the upstream channel is not used for ordinary payload communication, it can be divided into two or more equally sized sub-slots for transmitting control information. A communication unit can communicate by transmitting a request packet in one of the sub-slots of a time slot not previously assigned for payload communication. The base station receives such request packets, determines how many time slots are necessary for the communication unit to communicate, and transmits a control packet in a time slot of the downstream channel indicating which slots are assigned to the communication unit. The communication unit then transmits its packets in its assigned time slot. No contention resolution protocol is specified for transmitting reservation requests. Nor does this patent explain how a communication unit determines that a time slot of the upstream channel is not assigned for payload communication. Finally, note that the upstream channel cannot carry both reservation request packets and payload packets simultaneously. The upstream channel capacity is therefore allocated to

each of these kinds of packets thereby reducing the utilization of the upstream channel for carrying payload information.

U.S. Patent No. 5,012,469 discloses a satellite communications network. The satellite communications network includes plural earth stations that communicate with a satellite station. The communication is bidirectional using a single contentious channel. The channel is time division multiplexed according to one of a number of different formats depending on the traffic load. According to one format, under certain circumstances, the channel is divided into "large slots" which include one payload time slot and a fixed number of mini-slots. Each mini-slot is uniquely assigned to the earth stations for writing reservation request packets (requesting reservation of payload time slots) for transmission to the satellite station. Under other circumstances, the channel is divided into payload time slots only, and the payload time slots are uniquely assigned to each earth station. As circumstances, such as the traffic load, change, the channel is formatted according to the appropriate one of the two formats. According to a second format, the channel is formatted in one of three different ways, including the two formats mentioned above and a third format in which the channel is divided into time slots which are accessed by the earth stations in a contentious fashion. Again, the channel is formatted according to one of the three different formats depending on the circumstances. In addition to the disadvantages mentioned above for the wireless and cable networks, the architecture suggested in this patent is highly complex.

It is an object of the present invention to overcome the disadvantages of the prior art.

## Summary of the Invention

This and other objects are achieved by the present invention. Illustrative environments of use of the present invention are a wireless network, a satellite network, a cable network, etc. In a cable network, a head end is provided as a central controller, a shared medium is provided and multiple stations, namely, subscriber stations, are connected to the head end via the shared medium. Illustratively, the head end transmits one or more traditional broadcast video programs by modulating them onto one or more carrier signals and transmitting the carrier signals on the shared medium. Such traditional broadcast programs may thus be contemporaneously received at each subscriber station. Frequency bands not used for traditional broadcast video programming are assigned for providing point-to-point or multicast communication.

To provide such point-to-point or multicast communication, according to the invention, three types of communication channels, namely, one or more upstream payload channels, one or more upstream control channels and one or more downstream channels, are allocated. Illustratively, the carrier signal of the channels furthermore have mutually non-overlapping bands. Each bitstream is furthermore illustratively organized into packets.

The multiple access network can be formed by assigning the channels with channel identifiers and complete descriptions of the channel profiles, such as carrier frequencies, symbol rates, burst parameters, etc., so that the stations and central controller can communicate. Together with a network ID, a network configuration control message is transmitted by the central controller to all the stations attached to the medium. A minimum of three channels are needed to define the network (DCPC, UCC and UPC). Additional channels can be added to the network by the central controller. Any change in configuration is communicated to the stations using network configuration messages. Further, all control messages to the stations are uniquely identified by the network ID, channel ID, station ID and mini-slot ID, allowing flexibility to either increase or decrease the network capacity and performance according to the needs of the network service providers.

Each channel illustratively is divided into slots or mini-slots. Each upstream payload channel is assigned for carrying upstream directed payload bitstreams from the stations to the central controller. Each upstream control channel is assigned for carrying upstream directed control bitstreams, such as reservation request bitstreams requesting reservation of time slots of the upstream payload channel, from the stations to the central controller. Each downstream channel is assigned for carrying at least downstream directed control bitstreams, such as bitstreams containing acknowledgments and also containing indications of assigned slots in the upstream payload channel, from the central controller to the stations. Each downstream channel illustratively also carries the collision status of collided reservation request

mini-slots. The downstream channel may also illustratively carry payload bitstreams.

Illustratively, stations may write reservation request bitstreams into mini-slots of the upstream control channel. Such reservation request bitstreams are received by the central controller, which responds by assigning specific slots to each station. The central controller writes control bitstreams in the downstream channel indicating the slot assignment which are received by the respective stations that issued the reservation request bitstreams. Each station then writes its payload bitstreams only in assigned slots of the upstream payload channel. Illustratively, the payload bitstreams are received by the central controller. If the received payload bitstreams are destined to a station in the network, the central controller writes such payload bitstreams into slots of the downstream channel. Each station receives the payload bitstreams transmitted in the downstream channel, accepts the bitstreams destined thereto, and discards each other payload bitstream.

According to one embodiment, a station communicates on a shared medium of a network as follows. The station transmits a bitstream containing a request to reserve one or more slots of an upstream payload channel on an upstream control channel. The station then receives multiple bitstreams from a downstream channel, including at least one bitstream containing an indication of one or more slots of the upstream payload channel assigned to the station for transmitting packets. The station then transmits payload bitstreams on the upstream payload channel, but only at

the assigned slots of the upstream payload channel. In this embodiment, the bitstreams are carried simultaneously on the upstream control channel and the upstream payload channel of the shared medium during overlapping time periods.

According to another embodiment, a central controller of a network enables communication of bitstreams from a station via a shared medium of the network as follows. The central network controller receives from an upstream control channel, a reservation request bitstream, requesting reservation of slots for a particular station. The central network controller transmits on a downstream channel, a bitstream including an indication of one or more slots assigned to the particular station. The central network controller receives a bitstream from one of the assigned slots of an upstream payload channel. Again, in this embodiment, the bitstreams are carried simultaneously on the upstream control channel and the upstream payload channel of the shared medium during overlapping time periods.

By transmitting reservation request packets and upstream directed payload packets on separate "simultaneous" channels, each channel can be utilized to its fullest potential. For example, different modulation techniques can be used on each channel, such as BPSK, QPSK, n-QAM, orthogonal frequency division multiplexing (OFDM), discrete multi-tone modulation (DMT), discrete wavelet multi-tone modulation (DWMT), code division multiple access (CDMA), synchronous code division multiple access (SCDMA), etc. This maximizes efficiency of the upstream payload channel yet ensures high reliability and short mini-slot size on the upstream control

channel. By reducing the mini-slot size, the likelihood of collision on the upstream control channel decreases, and retransmission delays in the event of collisions can be overall reduced (depending on the collision resolution technique utilized). Likewise, by removing mini-slots from the upstream payload channel, the channel utilization for payload packets is maximized, even while using higher spectral efficiency modulation techniques. Thus, the competing demands of reservation request packets and payload packets can be satisfied without detriment to each other.

In a further embodiment, reservation request and payload packets are not transmitted simultaneously but sequentially, since they are transmitted by a single upstream programmable RF transmitter. In this embodiment, a first switch switches between forwarding modulated UPC and UCC signals to a single frequency agile tuner, while a second switch switches between forwarding an indication of the selected carrier signal f2 and f3, respectively.

The multiple access method can simplify multiple channel support for expanded bandwidth demand and can maximize the number of supported subscriber stations. To increase the capacity, each upstream payload channel or each downstream payload channel can be added to the network. To minimize contention and lower the access delay of the multiple access network, the stream of mini-slots in the upstream control channel can be enhanced by allocating a wider bandwidth, or assigning some subscriber stations to different upstream control channels.

**Brief Description of the Drawing**

FIG 1 shows a conventional HFC cable network.

FIG 2 shows a conventional logical bus assignment of channels in a HFC cable network.

FIG 3 shows a conventional allocation of carrier frequencies and bands to channels.

FIG 4 shows a conventional mini-slot frame.

FIG 5 shows a conventional division of an upstream channel into slots and mini-slots using different modulation techniques.

FIG 6 shows conventional fixed and dynamic patterns for dividing the upstream channel into slots and mini-slots.

FIG 7 shows a logical bus network according to the present invention.

FIG 8 shows an allocation of frequencies to channels according to an embodiment of the present invention.

FIG 9 shows upstream control channel UCC and upstream payload channel streams according to an embodiment of the present invention.

FIG 10A shows circuitry in a subscriber station according to an embodiment of the present invention.

FIG 10B shows circuitry in an upstream RF transmitter according to another embodiment of the present invention.

FIG 11 shows an illustrative packet structure for packets transmitted in the downstream channel for use in the circuitry of FIGs 10A and 10B.

FIGs 12-13 show a flow chart of a process executed by a subscriber station according to an embodiment of the present invention.

FIG 14 shows circuitry in a head end according to an embodiment of the present invention.

FIG 15 shows a flow chart of a process executed by a head end according to an embodiment of the present invention.

FIG 16 shows a graph comparing payload efficiency of the present invention to the prior art.

## Detailed Description of the Invention

The present invention may be implemented in any kind of network, such as a wireless network, a satellite network, a cable network, etc. For sake of convenience, this invention is illustrated in detail for a two way HFC cable network (HFC network) having a tree and branch physical topology, similar to the conventional topology shown in FIG 1. As such, the present invention is readily usable with existing cable networks with limited modification for two-way operation. In this illustration, the central controller is the head end, the stations are the subscriber stations and the shared medium is the optical fiber and coaxial cabling that connects the head end, fiber nodes and subscriber stations.

According to the invention, three types of communication channels are provided (in addition to the other channels for carrying traditionally broadcast programs in the downstream direction). The three types of communication channels are a downstream control and payload channel DCPC, an upstream control channel UCC and an upstream payload channel UPC. At least one of each type of the three channels described is needed

for the communication network in this invention. A logical network configuration according to the present invention is shown in FIG 7. In one embodiment (e.g., FIG 10A), the upstream control channel UCC and the upstream payload channel UPC can carry bitstreams from a single SS simultaneously. That is, different bitstreams may be simultaneously carried on the upstream payload channel UPC and the upstream control channel UCC during overlapping periods of time. Such "simultaneous" channels can be defined using a number of modulation techniques such as FDM, OFDM, DMT, DWMT, CDM, FM, etc. For sake of illustration this invention is illustrated using an FDM technique wherein each of the three communication channels DCPC, UPC and UCC has a unique carrier frequency, f1, f2 or f3, respectively, and mutually non-overlapping bands, as shown in FIG 8. For example, the UCC and UPC channel bands are located between 5 and 42 MHZ whereas the DCPC channel band is between 54 and the upper cut-off frequency of the cable network (typically 750 MHZ, but can be as high as 1 GHZ). Each downstream channel, including the downstream control and payload channels DCPC are allocated bands in units of 6 MHZ (in North America, according to NTSC TV channel convention). The upstream channels, including the upstream control channel UCC and the upstream payload channel UPC are allocated bands of various bandwidths, typically from 100 KHz to 6 MHZ, wherever a low noise sub-band in the band from 5-42 MHZ can be found.

Referring again to FIG 7, the downstream control and payload channel DCPC serves the same purpose as the downstream channel DC in FIG 2 and is divided into slots. The upstream control channel UCC is divided into mini-slots only for carrying control packets such as reservation request packets. On the other hand, the UPC is divided into slots only for carrying payload packets. As before, SSs 150 can write in one of the designated slots according to a retransmission rule of the upstream channels UPC and UCC and can only read packets from the slots of the downstream control and payload channel DCPC. Likewise, the head end 112 can only write packets in the slots of the downstream control and payload channel DCPC and can only read packets from the slots and mini-slots of the upstream channels UPC and UCC. Furthermore, the SSs 150 can write packets only in assigned slots of the upstream payload channel UPC. The SSs 150 can also freely write packets in mini-slots of the upstream control channel UCC, designated according to a retransmission rule, subject only to contention from the other SSs 150. Alternatively, the mini-slots may be accessed in a contention free manner by polling the SSs 150 or by uniquely and fixedly assigning each mini-slot to each SS 150. In yet another scheme, a mix of contentious and fixedly assigned mini-slots are provided.

Thus, unlike the channel architecture of FIGs 2 and 3, the channel architecture of FIGs 7 and 8 requires that contention free transmission of upstream directed payload packets in slots and contentious transmission of upstream directed reservation request packets in mini-slots occur in different frequency division modulated channels in different frequency bands. This is

illustrated in FIG 9, wherein the upstream payload channel UPC carries a stream of only payload packets in slots (which may be fixed or variable in size). Simultaneously, the upstream control channel UCC carries a stream of only reservation request packets in mini-slots (which illustratively are of a fixed size). As such, in one illustrative embodiment (e.g., in the circuitry of FIG 10A, to be described in greater detail below), both kinds of transmissions can occur simultaneously, without interfering with each other or otherwise constraining each other. For instance, the packets transmitted on the upstream payload channel UPC may be n-QAM (where n = 16, 64, 256,...), QPSK, etc., modulated and the packets transmitted on the upstream control channel UCC may be BPSK, QPSK, ... etc. modulated. As such, the mini-slot frames may begin with relatively shorter preambles (not shown). Each control packet written in a mini-slot frame may include a subscriber station address or identifier, an identifier of the type of communication for which the slot(s) is (are) requested, the size or number of slots requested and other information (e.g., error check and/or correction codes or sequences, etc.).

FIG 10A shows the circuitry in a subscriber station 150 used to adapt the subscriber station 150 according to one embodiment of the invention. FIG 10A does not show conventional circuitry which also may be present in a subscriber station 150 for receiving traditional broadcast channels, for transmitting requests to receive pay-per view events, for processing data, for receiving and digitizing voice or video, etc. The coaxial drop line 22 is connected to a diplexer 152. The diplexer 152 separates the downstream

receive channel bands from the upstream transmit channel bands. The downstream channel signals, including the downstream control and payload channel DCPC signal, are outputted to a downstream RF receiver 154. Likewise, the upstream control channel and upstream payload channel signals (if any are present) outputted from the upstream RF transmitters 156 are combined by the diplexer 152 for output onto the coaxial drop line 22.

The received signals outputted from the diplexer 152 to the downstream RF receiver 154 are inputted to a frequency agile tuner 158. As shown, the frequency agile tuner 158 receives a signal indicating the carrier frequency (or center frequency) selection of f1 and channel bandwidth thereby causing the frequency agile tuner 158 to filter out only the downstream control and payload channel DCPC frequency band.

The filtered out downstream control and payload channel DCPC signal is inputted to a receiver/demodulator, forward error corrector, deinterleaver and decoder 160. The receiver circuit 176 performs the inverse functions of the transmitter circuit 260 (see FIG 14). Illustratively, some of these subcircuits are optional and are merely included for sake of illustration. See ITU-T Recommendation J.83, Digital Multi-Programme Systems for Television Sound and Data Services for Cable Distribution, Oct., 1995. The circuit 160 includes a receiver/demodulator which receives and demodulates the packet data from the carrier signal (or signals) assigned to the downstream control and payload channel DCPC. Such received packets are outputted to a subscriber media access control circuit 162.

The subscriber media access control circuit 162 outputs payload packets and reservation request packets at the appropriate time to the upstream RF transmitters 156. Payload packets are received at an encoder, interleaver, forward error corrector and modulator 176. The forward error corrector adds forward error correction bits to the packet data. The modulator modulates the packet onto a carrier signal, e.g., using a QPSK modulation technique, a 16, 64 or 256-QAM modulation technique, etc. The modulated carrier signal is outputted to a frequency agile tuner 178. The frequency agile tuner 178 also receives an indication of the carrier signal or center frequency f2 and bandwidth assigned to the upstream payload channel UPC. In response, the frequency agile tuner 178 shifts the modulated carrier signal to the band assigned to the upstream payload channel UPC. Illustratively, the indication of the frequency can be varied to change the frequency band to which the frequency agile tuner 178 shifts the modulated signal e.g., to avoid noisy portions of the 5-42 MHZ band.

The reservation request packets are outputted from the subscriber media access controller 162 to an encoder and modulator 182. The encoder subcircuit of the circuit 182 may perform a different encoding than the encoder subcircuit of the circuit 176 performs, which different encoding is appropriate for the particular modulation technique employed in the modulator 182. Illustratively, the modulator 182 modulates the reservation request packet using a BPSK or QPSK modulation technique. The modulated signal is outputted to frequency agile tuner 184. As shown, the frequency agile tuner 184 receives an indication of the frequency f3 assigned to the

upstream control channel UCC. As such, the frequency agile tuner 184 shifts the modulated signal to the frequency band assigned to the upstream control channel UCC. Like the frequency agile tuner 178, the indication of the frequency can be varied so that the frequency agile tuner 184 shifts the modulated signal to a selectable frequency band.

The modulated carrier signals for the upstream payload channel UPC and the upstream control channel UCC are inputted to an RF amplifier 180. The RF amplifier 180 outputs the amplified upstream payload channel UPC and upstream control channel UCC signals to the diplexer 152. The diplexer 152 outputs the upstream payload channel UPC and upstream control channel UCC signal onto the coaxial drop line 22 for transmission to the head end 112 (FIG 7).

The filtered out downstream control and payload channel DCPC signal is inputted to a demodulator, forward error corrector, deinterleaver and decoder 160. Illustratively, not all of these subcircuits are needed to implement the invention. The circuit 160 includes a demodulator/ receiver which demodulates the packet data from the carrier signal (or signals) assigned to the downstream control and payload channel DCPC.

The subscriber media access controller 162 may be implemented using one or more integrated circuit chips. The subscriber media access control circuit 162 can be implemented using a programmable processor or a finite state automata. Below, the subscriber media access control circuit 162 is described as containing several subcircuits for sake of convenience.

FIG 10B shows an alternative embodiment upstream RF transmitters 156. Specifically, single upstream RF programmable transmitter 356 is shown, which may be used in subscriber station 150 of FIG 10A. Illustratively, single upstream RF programmable transmitter may be implemented from a commercially available transmitter chip, such as the STEL 1109.

Similar to the description of FIG 10A, the subscriber media access control circuit 162 outputs payload packets and reservation request packets at the appropriate time to the single upstream RF transmitter 356. Payload packets are received at a UPC burst profile circuit 376, while control packets are received at a UCC burst profile circuit 382. Each burst profile circuit includes parameter pertaining to the symbol rate, the modulation, the burst preamble (such as the length and pattern of the burst), error checking and/or forward error-correcting code (FEC), and an inter-burst guardband to account for the timing skew, ramping up and down of the transmitter. Transmitter 356 also includes a carrier frequency selection circuit 385 which outputs either a payload carrier frequency selection f2 or a control carrier frequency selection f3. In addition, transmitter 356 includes first and second switches 310 and 315, respectively. First switch 310 is coupled between burst profile circuits 376, 382 and a frequency agile tuner 390. Second switch 315 is coupled between carrier frequency selection circuit 385 and tuner 390. Tuner 390 is also coupled to RF amplifier 380, that is similar to RF amplifier 180 in FIG 10A.

In operation, when an upstream payload bitstream is received from subscriber media access control circuit 162, it is supplied to UPC burst profile circuit 376. The UPC burst profile circuit processes the bitstream according to its parameters. For example, using FEC parameters, the burst profile circuit adds forward error correction bits to the packet data. Further, using modulation parameters, the burst profile circuit modulates the packet onto a carrier signal. The modulated carrier signal is then outputted to frequency agile tuner 390, via switch 310. Simultaneously, the frequency agile tuner also receives an indication of the carrier signal or center frequency f2 and bandwidth assigned to the upstream payload channel UPC from carrier frequency selection circuit 385, via switch 315. In response, the frequency agile tuner 378 shifts the modulated carrier signal to the band assigned to the upstream payload channel UPC. Illustratively, the indication of the frequency can be varied to change the frequency band to which the frequency agile tuner 178 shifts the modulated signal e.g., to avoid noisy portions of the 5-42 MHZ band.

The reservation request (control) packets are outputted from the subscriber media access controller 162 to UCC burst profile circuit 382. As with UPC burst profile circuit 376, the UCC burst profile circuit processes and modulates the bitstream according to its parameters. The modulated carrier signal is then outputted to frequency agile tuner 390, via switch 310. Simultaneously, the frequency agile tuner also receives an indication of the carrier signal or center frequency f3 and bandwidth assigned to the upstream payload channel UCC from carrier frequency selection circuit 385, via switch

315. In response, the frequency agile tuner 378 shifts the modulated carrier signal to the band assigned to the upstream payload channel UCC.

The modulated carrier signals for the upstream payload channel UPC and the upstream control channel UCC are inputted to RF amplifier 380. The RF amplifier 380 outputs the amplified upstream payload channel UPC and upstream control channel UCC signals to the diplexer 152. The diplexer 152 outputs the upstream payload channel UPC and upstream control channel UCC signal onto the coaxial drop line 22 for transmission to the head end 112. However, unlike the transmitter of FIG 10A, due to the inherent time delay that the embodiment of FIG 10B incurs (due to the channel switching delay of switches 310 and 315), the head end may take such delay into account when scheduling and granting the reservation or payload burst transmission.

Illustratively, packets received from the downstream control and payload channel are MPEG-2 transport stream packets into which other message packets, packet fragments or cells may be inserted, such as is shown in FIG 11. According to the MPEG-2 systems standard, each transport packet is 188 bytes long with a four byte header and a 184 byte message carrying portion (commonly referred to as "payload" which should be distinguished from the usage of the term payload herein). The MPEG-2 transport stream packet includes a synchronization word and a 13-bit packet identifier or "PID." Other control information is also present in the transport stream packet header. A group of reserved PIDs will be used by circuit 162 to separate the MPEG-2 payloads (carrying digital video programs) from

other types of control and data (such as Internet packet segments, ATM cells or STM bitstreams).

The message carrying portion of the packet includes, illustratively, two types of packets, namely, a "control" packet and a "payload" packet. The downstream control demultiplexer 166, demultiplexes the control packet. The control packet includes a network configuration message which contains a network ID, the DCPC channel ID, the UCC channel ID and the UPC channel ID that together defines the multiple access network. Additional channel IDs may also be included as needed. All necessary channel information and parameters needed to configure the station transmitters and receivers are broadcasted to all stations using additional control messages. The station will transmit its upstream packets using the pre-configured channels.

The station monitors the control messages from the central controller. The mini-slot collision status feedback control message will uniquely identify the status of mini-slot transmission by using the network ID, UCC channel ID and mini-slot ID. Likewise, the bandwidth reservation grants, transmitted to the station, are uniquely identified by the network ID, a per-grant station ID (which includes an address or identifier of the destination station), while the granted time slots the payload transmission are uniquely identified by the UPC channel ID, start of mini-slot ID and number of slots granted. One or more grants can be sent within grant message. In addition, the control packet may include other control information.

As shown in FIG 11, the bandwidth reservation grant field may include in each reservation grants, #1 to #N, an ID of the subscriber station receiving the reservation grant, a UPC channel ID, a transmit start mini-slot ID field and a number of slots granted field. The UPC channel ID includes an address or identifier of the destination SS. The subscriber media access controller 162 determines whether or not the address in this ID field matches the address of the SS 150 in which the subscriber media access controller 162 resides or a multicast address of a multicast group to which this SS 150 has subscribed. If not, the control information in the transmit start slot ID field and number of slots granted field are destined to another SS and this information is discarded. If the addresses match, the information in the transmit start slot ID field and number of slots granted field is destined to the SS 150 in which the subscriber media access controller 162 is located and the information is processed as described below.

The downstream payload demultiplexer 164 demultiplexes and reassembles the packet data in the payload packet. The payload packet may contain messages, Internet packet segments, a synchronous transfer mode (STM) bitstream, asynchronous transfer mode (ATM) cells, etc. Using header information in the payload packet, the subscriber media access controller 162 determines whether the payload packet data is destined to the SS 150 in which the subscriber access media controller 162 resides, and therefore should be accepted, or whether the payload packet data is destined to another SS and should be discarded.

Referring back to FIG 10A, the subscriber media access controller 162 also includes a transmit scheduler 168, a retransmission rule decision circuit 170, an upstream payload multiplexer 172 and a reservation request packet generator 174. The operation of the circuits 168, 170, 172 and 174 are now described with reference to FIGs 12-13. In a first step S1, the transmission scheduler 168 performs certain initialization procedures. For instance, the transmission scheduler 168 receives from the control packets indications of available mini-slots, assigned slots and other information regarding timing. (The additional information may be a uniform system time clock maintained by the head end 112 which periodically transmits packets containing "snapshots" of the system time clock (time stamps) to the SSs 150. For example, the technique used in MPEG-2 systems for re-establishing the system time clock using program clock references or PCR's may be used to synchronize the SS clock to the head end clock. See ISO/IEC 13818-1: Generic Coding of Moving Pictures and Associated Audio, Part 1: Systems.) In a next step S2, the transmit scheduler 168 determines whether or not a pending queue (not shown) contains payload data waiting for transmission. If not, step S1 is repeated. If to-be-transmitted payload data is available, in step S3, the transmit scheduler 168 determines how much capacity is necessary to transmit the to-be-transmitted data (e.g., in terms of the number of mini-slot time periods, if slot sizes are allocated in such increments). Next, in step S4, the transmit scheduler 168 determines the next available mini-slot in which a reservation request packet may be transmitted. For example, the control packets demultiplexed from the

downstream control and payload channel DCPC include a start mini-slot identification indication and an indication of the number of mini-slots, in a group of mini-slots, beginning with the identified start mini-slot that are available for new reservation request packets. The start of the mini-slot boundary can be specified by an offset counter referenced to a synchronized timing marker at the head end 112 and at each SS 150. According to one technique, the transmit scheduler 168 generates a random number and determines whether or not the random number falls within the range of 1 to the number indicated as being in the group of available mini-slots. If not, the transmit scheduler 168 refrains from transmitting reservation request packets until a control message is received from the head end 112 indicating the next available group of mini-slots.

On the other hand, if the random number falls within the range, then, in step S5, the transmit scheduler 168, at the appropriate time, provides an indication of the needed slot capacity to the reservation request packet generator 174. In response, the reservation request packet generator 174 generates a reservation request packet including the address or identifier of the SS 150, the requested slot capacity and the type of communication data to be communicated in the requested slots. The reservation request packet generator 174 is activated by the transmit scheduler 168 so as to output the reservation request packet at the specified time for transmission in the upstream control channel at the particular mini-slot, of the next group of available mini-slots, indicated by the random number generated by the transmit scheduler 168. (The actual transmission time of the request packet

may be delayed from the time of the leading boundary of the corresponding mini-slot in which the reservation request packet is transmitted. The delay time may be the difference between the SS to head end propagation delay time at this particular SS 150 and the maximum SS to head end propagation delay time.) The net result is that mini-slot bursts from all SSs will arrive at the head end controller receiver tuners 258, 259 with minimum skew. Next, in step S6, the reservation request packet generator 174 then signals the retransmission rule decision circuit 170 to set its acknowledgment timer and begin counting. The retransmission rule decision circuit 170 responds by setting an appropriate timer and counting down the timer. The timer is illustratively set to expire after a time period exceeding the worst case feedback delay, equal to the round-trip propagation delay plus the processing delay at the head end 112 and SS 150, between transmitting reservation request packets and receiving acknowledgment packets in response. In step S7, the retransmission rule decision circuit 170 waits for an acknowledgment control packet to be received by the downstream payload demultiplexer 164. The retransmission rule decision circuit 170 responds to one of the following events:

(1) The timer expires (step S8). Illustratively, this indicates that the reservation request message was not received. In response, the retransmission rule decision circuit 170 causes the transmit scheduler 168 to schedule the reservation request packet generator 174 to retransmit the reservation request packet at the next available mini-slot of the upstream control channel

UCC. This is achieved by step S9 which causes execution to return to step S4.

(2) Before the timer expires, a message is received from the head end 112 via the downstream control and payload channel DCPC indicating that a collision has occurred (steps S9-S11). For example, such an indication may be present in the mini-slot collision status field of a control packet received on the downstream control and payload channel DCPC (FIG 12). In response, in step S12, the retransmission rule decision circuit 170 updates its collision resolution algorithm parameters (e.g., the persistent parameter, the next available collision resolution mini-slot, etc.) The retransmission rule decision circuit 170 furthermore determines whether or not to reattempt to transmit the reservation request packet. Assuming the retransmission rule decision circuit 170 determines to reattempt transmission, the transmission rule decision circuit 170 determines when to perform such a retransmission in step S13 and schedules the retransmission in step S14. At the appropriate time, steps S17, S5-S7 are performed whereby the transmit scheduler 168 causes the reservation request packet generator 174 to regenerate the reservation request packet and retransmit it at the next available mini-slot on the upstream control channel UCC available for collided reservation request packets. This

also causes the retransmission rule decision circuit 170 to stop the timer (step S9).

(3) Before the timer expires, a message is received in a control packet transmitted from the head end 112 via the downstream control and payload channel DCPC acknowledging receipt of the reservation request packet but indicating that no slots are currently available for assignment (steps S9-S11, S13). Illustratively, this causes the retransmission rule decision circuit 170 to stop the timer (step S9) and wait for the grant control message indicating which slots are assigned to the SS 150 (step S15).

(4) Before the timer expires, a message is received in a control packet transmitted from the head end 112 via the downstream control and payload channel DCPC acknowledging receipt of the reservation request packet and assigning specific slots for transmission (steps S9, S15). For example, such information may be present in the transmit start slot ID and number of granted slots fields of a received control packet (FIG 11). This also causes the retransmission rule decision circuit 170 to stop the timer (step S9).

In response to receiving a grant control packet that assigns one or more slots to the SS 150, the transmit scheduler 168 schedules the pending to-be-transmitted data residing in the queue for transmission in step S15. At the appropriate time, the data is segmented into packets by the upstream

payload multiplexer 172 and outputted to the encoder, interleaver, forward error corrector and modulator circuit 176, under control of the transmit scheduler 168. The transmit scheduler uses the internal system clock, the start slot indication and number of granted slot indications received in control packets by the downstream control demultiplexer 166 to properly synchronize the segmentation and modulation of packet data with the assigned slot(s). (Again, the actual transmission may be delayed from the leading slot boundary by a particular delay equal to the difference between the head end 112 to SS 150 propagation delay for this SS 150 and the maximum head end 112 to SS propagation delay.) Afterwards, in step S 16, an accounting is made of the remaining to-be-transmitted data in the queue and processing returns to step S1.

Referring now to FIG 14, a circuit for adapting a head end controller of a head end 112 is shown. The head end 112 has a downstream RF transmitter 256, an upstream payload channel RF receiver 254 and an upstream control channel RF receiver 255. The downstream RF transmitter 256 receives packets at an encoder, interleaver, forward error corrector and modulator circuit 260. This circuit 260, amongst other things, modulates packets onto a carrier signal for transmission. The modulated carrier signal is outputted to a frequency agile tuner 278 which also receives an indication of the carrier or center frequency f1. The frequency agile tuner 278 shifts the modulated carrier signal to the downstream control and payload channel DCPC band. The RF amplifier 280 amplifies the signal and outputs the amplified signal to diplexer 252. Diplexer 252 combines the downstream

control and payload channel signal thus generated with the other signals carried on coaxial link 34.

The diplexer 252 also splits off the upstream directed signals 253 from the signals carried on the coaxial link 34. The upstream payload channel RF receiver 254 has a frequency agile tuner 258 that receives the upstream directed signals, an indication of the carrier or center frequency f2 and an indication of the bandwidth of the upstream payload channel UPC. As such, the frequency agile tuner 258 filters out the upstream payload channel UPC signal. The filtered out upstream payload UPC channel signal is inputted to a burst demodulator, forward error corrector and decoder circuit 276. Amongst other things, the circuit 276 demodulates and receives each payload packet from the upstream payload channel UPC and outputs each payload packet to the head end media access controller 262.

Likewise, the upstream control channel RF receiver 255 has a frequency agile tuner 259 that receives the upstream directed signals outputted from the diplexer 252, an indication of the carrier or center frequency f3 and an indication of the bandwidth of the upstream control channel UCC. As such, the frequency agile tuner 259 filters out the upstream control channel UCC signal. The filtered-out signal is inputted to a burst demodulator and decoder circuit 282. Amongst other things, the circuit 282 demodulates each control packet from the upstream control channel UCC and outputs each control packet to the collision detector 290. As shown, the collision detector 290 is connected to a reservation request register 292 and a mini-slot collision status queue 294. In response to

detecting a collision, collision status information is inputted to the collision status register 294. In response to receiving a reservation request packet, information regarding the reservation request, e.g., the address of the requesting SS, the amount of requested slot capacity, etc., is stored in the reservation request register 292.

The head end media access controller 262 is shown as including an upstream synchronizer 230, a resource allocator 232, a contention resolution circuit 234 and a packet filter and forward circuit 236. While shown as separate circuits, the head end media access controller 262 can also be implemented with a suitably programmed processor.

The purpose of the packet filter and forward circuit 236 is to receive payload packets from within the cable network and from other networks 230 and to forward such packets to the correct destination. Packets destined outside of the cable network are transmitted to one of the other attached networks 30. Packets destined to a SS 150 are enqueued in downstream transmitted data buffer 240 for transmission on the payload bitstreams of downstream control and payload channel DCPC.

The purpose of the upstream synchronizer 230 is to maintain a system clock and to periodically broadcast time stamps of the system clock to the SSs 150 so that all station system clocks and the head end system clock are synchronized. Once synchronized, station MACs 162 will know the precise mini-slot location by referencing the offset value to the time-stamp value broadcasted down the DCPC. The upstream synchronizer 230 also synchronizes the transmission of packets on the downstream control and

payload channel DCPC. In addition, several different kinds of packets may be available for transmission in the downstream transmitter data buffer 240 which may be stored in separate queues. The upstream synchronizer 230 judiciously selects from amongst the different types of enqueued packets depending on their type and their respective urgency for output from the downstream transmitter data buffer 240. As noted above, the packets transmitted on the downstream control and payload channel DCPC may be MPEG-2 transport stream packets containing specific PIDs, control packets and payload packets. The upstream synchronizer 230 segments enqueued packets and reassembles them into MPEG-2 transport stream packets as necessary. However, this is only illustrative; other multiplexing and encoding schemes can be used.

The purpose of the resource allocator 232 is to keep track of resources and allocate them in a fair and orderly manner or according to the priority of each communication for which resources are allocated. Most notably, the resource allocator 232 keeps track of allocated slots on the upstream payload channel UPC and ensures that each slot is allocated only to a single SS 150. The allocation technique employed by the resource allocator 232 can be quite intricate wherein slots are allocated on a prioritized basis depending on the type of communication for which each SS 150 has requested to reserve slots.

The purpose of the contention resolution circuit 234 is to generate a control packet message when a collision occurs. The contention resolution circuit 234 may also maintain statistics on the number of collisions, which

statistics may in turn be used to control when to broadcast a start available mini-slot for new reservation requests or how many mini-slots to make available in a group of mini-slots for new reservation requests. The contention resolution circuit 234 therefore controls how many residual mini-slots are available for retransmitting collided reservation request packets.

The slot allocation operation of the head end circuitry 112 will now be described with reference to FIG 15. In step S20, the upstream control channel RF receiver 255 receives a modulated signal from the upstream control channel and demodulates a reservation request control packet therefrom. In step S21, the collision detection circuit 290 receives a reservation request packet from the upstream control channel RF receiver 255. Next, the collision detector determines whether or not a collision has occurred, e.g., by performing an error check on the received reservation request packet. In step S22, the collision detection circuit 290 updates the collision status register to indicate whether or not a collision has occurred. In step S23, if a collision has occurred, then in step S24, the contention resolution circuit 234 updates various contention resolution parameters (e.g., number of collisions, etc.). The contention resolution circuit 234 furthermore enqueues a collision detected control packet into the downstream transmitter data buffer 240. In step S25, the collision detected control packet is outputted to the downstream RF transmitter 256 for transmission at the appropriate time slot of the downstream control and payload channel DCPC under the control of the upstream synchronizer 230. Processing then returns to step S20.

In step S23, if no collision has occurred then the resource allocator 232 determines whether or not sufficient resources (e.g., slots of the upstream payload channel UPC) are available for allocating slots to the requesting SS 150 (step S26). If not, then in step S27 the resource allocator 234 notes the request as pending and generates a grant pending acknowledgment control packet which is enqueued in the downstream transmitter data buffer 240. The grant pending acknowledgment control packet is outputted to the downstream RF transmitter 256 for transmission at the appropriate time slot of the downstream control and payload channel DCPC under the control of the upstream synchronizer 230. Processing then returns to step S20.

If in step S26, the resource allocator 234 determines that sufficient resources are available for satisfying the reservation request, then processing proceeds to step S28. In step S28, the resource allocator 234 assigns resources, i.e., slots, to the SS 150 that transmitted the reservation request. The resource allocator 234 then generates a slot assignment acknowledgment control packet indicating the slots which were assigned to the requesting SS 150. As noted above, such a packet includes the identifier or address of the requesting SS 150, the identifier of the starting slot in the upstream payload channel UPC assigned to the requesting SS 150 and the slot capacity (e.g., measured by the number of mini-slot lengths of the assigned slot) assigned to the SS 150. The resource allocator 234 enqueues the slot assignment acknowledgment control packet thus generated in the downstream transmitter data buffer 240. The slot

assignment acknowledgment control packet is outputted to the downstream RF transmitter 256 for transmission at the appropriate time slot of the downstream control and payload channel DCPC under the control of the upstream synchronizer 230. Processing then returns to step S20.

FIG 16 shows a graph of payload efficiency for the present invention and the prior art. As shown, as higher order QAM techniques are used, a larger fraction of the communication bandwidth is allocated for mini-slots in the prior art. In contrast, according to the invention, all of the bandwidth in the upstream payload channel UPC is allocated for payload packets. Thus, no reduction in bandwidth occurs as higher order QAM techniques are employed. Other advantages achieved by the invention include:

(1) Because the upstream control and payload bitstreams are separated into different channels, each channel can be individually optimized for the best mode of operation. For example, the upstream control channel, requiring relatively low bit rate and short mini-slot bursts, is best served by a robust modulation scheme with relatively narrow bandwidth that can be fit into the available narrow "gap" in the upstream spectrum with ingress noise. This preserves the wider available low noise bandwidth spectrum for upstream payload channels, which requires optimization for the highest efficiency with longer payload bursts.

(2) Note also that it is easier to increase the payload capacity by simply adding upstream payload channels. The head end does

not need equipment for such added upstream payload channels that can distinguish control information (i.e., mini-slot boundaries and contents) from payload information (i.e., slot boundaries and contents) for such added channels as in the conventional system. Similar reasoning applies to adding additional upstream control channels to accommodate additional subscriber stations. Thus, the inventive system is easier to expand.

(3) No complex system reconfiguration algorithm for repeatedly time dividing each upstream channel into both slots and mini-slots is needed. Thus, system robustness increases. This results, because subscriber stations need not periodically reconfigure the time division of the upstream channels to optimize channel utilization. Frequent reconfigurations will increase the probabilities of erroneous configuration of each subscriber station. Because such reconfigurations are not performed, the likelihood of erroneous reconfiguration by a subscriber station is decreased. In addition, less overhead in the downstream control and payload channel will be achieved because there is no need for frequent sending of reconfiguration messages down to the stations.

(4) The modulation technique for each of the upstream control and payload channels may be independently selected to optimize the robustness or information carrying capacity of that channel,

simplifying the introduction of advanced modulation technologies.

As noted above, the implementation of the invention in a cable network was merely illustrative. The invention may for instance be employed in a wireless network. In this case, the central controller is a base station, the subscriber stations are communication units such as cordless or cellular telephones or terminals and the shared medium is the air. The transmitters and receivers of the central controller and the communication units interface to the shared medium using radio antennae. Note that the subscriber stations may be stationary or mobile within the coverage area of the base station.

In another embodiment, the invention is employed in a satellite communication system. The central controller is a satellite, e.g., in geosynchronous orbit, the subscriber stations are earth stations and the shared medium is the air and space. The satellite includes a transponder and on-board controller. The transmitters and receivers of the earth stations and the transponder of the satellite interface with the shared medium using antennae.

As further noted above, different modulation techniques may be employed to achieve the upstream control and upstream payload channels that can simultaneously carry information. Some modulation schemes are single carrier modulation schemes such as QPSK and n-QAM. Other modulation schemes utilize multiple carriers, such as DMT, DWMT and OFDM. According to one technique, the upstream control and payload

channels are defined using FDM and SCDMA. According to such a definition, each channel is defined by one or more "orthogonal" code sequences. The sequences assigned to all of the channels are then modulated onto a single carrier across the bandwidth of the entire FDM channel.

The above discussion is intended to be illustrative of the invention. Those having ordinary skill in the art may devise numerous alternative variations of the invention without departing from the spirit and scope of the following claims.

## Claims

The claimed invention is:

1. A method for enabling a station to communicate via a shared medium of a network comprising the steps of:

(a) transmitting a bitstream containing a request to reserve one or more slots of an upstream payload channel on an upstream control channel,

(b) receiving a plurality of bitstreams from a downstream channel, including at least one bitstream containing an indication of one or more slots of said upstream payload channel assigned to said station for transmitting bitstreams, and

(c) transmitting payload bitstreams on said payload channel, only at said assigned slots of said upstream payload channel,

wherein bitstreams are carried simultaneously on said upstream control channel and said upstream payload channel of said shared medium during overlapping time periods.

2. The method of claim 1 further comprising the steps of:

(d) after beginning to perform step (a), receiving from said downstream channel a bitstream indicating that a collision occurred in said upstream control channel in performing said step (a), and

(e) in response, retransmitting said reservation request bitstream.

3. The method of claim 1 further comprising the steps of:

(d) prior to step (a), waiting until a bitstream is received from said downstream channel indicating the identity of an available group of one or more reservation slots in said upstream control channel,

(e) if data is available for transmission from said station, randomly determining, based on said indicated available group of reservation slots , whether or not to perform step (a), but only during one of said reservation slots of said indicated group of reservation slots.

4. The method of claim 1 further comprising the steps of:

(d) after performing step (a) but before step (b), setting an acknowledgment timer, and

(e) in response to said acknowledgment timer expiring before receiving a bitstream containing an acknowledgment from said downstream channel, repeating step (a).

5. The method of claim 4 further comprising the steps of:

(f) after performing step (d), but before performing step (e), receiving a bitstream from said downstream channel containing an acknowledgment of receipt of said reservation request but also indicating that no slots in said upstream payload channel are available for allocation, and

(g) refraining from repeating step (a) in said step (e).

6. The method of claim 1 further comprising the step of:

(d) receiving from said downstream channel a payload bitstream containing a communicated message originating from another station in said network.

7. The method of claim 1 wherein each of said bitstreams received from said downstream channel are organized into MPEG-2 transport packets.

8. The method of claim 1 wherein said upstream control channel, said upstream payload channel and said downstream channel each have a mutually different frequency band.

9. The method of claim 1 wherein said network is a cable network, said station is a subscriber station and said shared medium includes cabling.

10. The method of claim 1 wherein said network is a wireless network, said station is a communication unit and said shared medium is the air.

11. The method of claim 1 wherein said network is a satellite network, said station is an earth station and said shared medium comprises the air and space.

12. The method of claim 1 wherein said downstream channel is received by a plurality of stations via said shared medium.

13. The method of claim 1 wherein said upstream control channel and said upstream payload channel are multiple access channels.

14. The method of claim 1 wherein first and second modulation techniques are used for said upstream control channel and said upstream payload channel, respectively, said first modulation technique optimizing the robustness of said upstream control channel without degrading the robustness or utilization of said upstream payload channel.

15. The method of claim 1 wherein in step (a), said upstream control channel on which said bitstream containing said request is transmitted is one of plural upstream control channels.

16. The method of claim 1 wherein in step (b), said downstream channel on which said bitstream containing said indication is received is one of plural downstream channels.

17. The method of claim 1 wherein in step (c), said upstream payload channel on which said bitstream is transmitted is one of plural upstream payload channels.

18. In a central controller of a network, a method for enabling communication of bitstreams from a station via a shared medium of the network comprising the steps of:

(a) receiving from an upstream control channel, a reservation request bitstream, requesting reservation of slots for a particular station,

(b) transmitting on a downstream channel, a bitstream indicating one or more slots assigned to said particular station, and

(c) receiving a bitstream from one or more of said assign slots of an upstream payload channel,

wherein bitstreams are carried simultaneously on said upstream control channel and said upstream payload channel of said shared medium during overlapping time periods.

19. The method of claim 18 further comprising the steps of:

(d) detecting a collision during said step (a), and

(e) in response to said collision, transmitting a bitstream in said payload channel including a notification to at least said particular station that a collision occurred.

20. The method of claim 18 further comprising the steps of:

(d) transmitting on said downstream channel a bitstream including an indication of the occurrence of a group of one or more available slots on said upstream control channel.

21. The method of claim 18 further comprising the steps of:

(d) after step (a) but before step (b), in response to an absence of available slots in said upstream payload channel, transmitting a bitstream on

said downstream channel including an acknowledgment of receipt of said reservation request from said particular station but also including an indication that no slots of said upstream payload channel are currently available for allocation.

22. The method of claim 18 further comprising the steps of:

(d) receiving a payload bitstream from said upstream payload channel originating from a first station and destined to a second station, and

(e) transmitting said payload bitstream on said downstream channel.

23. The method of claim 18 wherein said upstream control channel, said upstream payload channel and said downstream channel each have a mutually different frequency band.

24. The method of claim 18 wherein said upstream control channel and said upstream payload channel are multiple access channels.

25. The method of claim 18 wherein said downstream channel is received by a plurality of stations via said shared medium.

26. The method of claim 18 wherein first and second modulation techniques are used for said upstream control channel and said upstream payload channel, respectively, said first modulation technique optimizing the

robustness of said upstream control channel without degrading a robustness or utilization of said upstream payload channel.

27. A method for communicating in a network comprising a central controller, a station and a shared medium for carrying signals between said central controller and said station, comprising the steps of:

(a) transmitting payload bitstreams from a station to the central controller on an upstream payload channel,

(b) transmitting reservation request bitstreams from the station to the central controller requesting reservation of one or more time slots in said upstream payload channel on an upstream control channel, and

(c) transmitting bitstreams from the central controller to the station indicating which slots of said upstream payload channel are assigned thereto a downstream channel,

wherein bitstreams are carried simultaneously on said upstream control channel and said upstream payload channel of said shared medium during overlapping time periods.

28. A circuit for enabling a station to communicate via a shared medium of a network comprising:

(a) a first transmitter for transmitting a bitstream containing a request to reserve one or more slots of an upstream payload channel on an upstream control channel,

(b) a receiver for receiving a plurality of bitstreams from a downstream channel, including at least one bitstream containing an indication of one or more slots of said upstream payload channel assigned to said station for transmitting bitstreams, and

(c) a second transmitter for transmitting payload bitstreams on said payload channel, only at said assigned slots of said upstream payload channel,

wherein bitstreams are carried simultaneously on said upstream control channel and said upstream payload channel of said shared medium during overlapping time periods.

29. The circuit of claim 28 further comprising:

a retransmission rule decision circuit for responding to said receiver receiving from said downstream channel a bitstream containing an indication that a collision occurred in said upstream control channel by causing said first transmitter to transmit said reservation request bitstream onto said upstream control channel again.

30. The circuit of claim 28 further comprising:

a transmit scheduler for waiting until said receiver receives a bitstream from said downstream channel indicating the identity of an available group of one or more reservation slots in said upstream control channel, and if data is available for transmission from said station, randomly determining, based on said indicated available group of reservation slots,

whether or not to cause said first transmitter to transmit said reservation request bitstream on said upstream control channel, but only during one of said reservation slots of said indicated group of reservation slots.

31. The circuit of claim 28 further comprising:

retransmission rule decision circuit for setting an acknowledgment timer, after said first transmitter transmits said reservation request bitstream on said upstream control channel and, in response to said acknowledgment timer expiring before said receiver receives an bitstream containing an acknowledgment from said downstream channel, causing said first transmitter to transmit said reservation request bitstream on said upstream control channel again.

32. The circuit of claim 31 wherein after setting said timer, but before said timer expires, said receiver receives a bitstream from said downstream channel containing an acknowledgment of receipt of said reservation request bitstream but also containing an indication that no slots in said upstream payload channel are available for allocation, and wherein, in response, said retransmission rule decision circuit refrains from causing said first transmitter to transmit said reservation request bitstream on said upstream control channel again.

33. The circuit of claim 28 wherein said receiver receives from said downstream channel a payload bitstream containing a communicated message originating from another station in said network.

34. In a central controller of a network, a circuit for enabling communication of bitstreams from a station on a shared medium of the network comprising:

(a) a first receiver for receiving from an upstream control channel, a reservation request bitstream, requesting reservation of slots for a particular station,

(b) a transmitter for transmitting on a downstream channel, a bitstream indicating one or more slots assigned to said particular station, and

(c) a second receiver for receiving a bitstream from one of said assigned slots of an upstream payload channel,

wherein bitstreams are carried simultaneously on said upstream control channel and said upstream payload channel of said shared medium during overlapping time periods.

35. The circuit of claim 34 further comprising:

a collision detection circuit for detecting whether or not a collision occurred in said reservation request bitstream received by said first receiver, and in response to detecting a collision, causing said transmitter to transmit a bitstream on said downstream channel containing a notification to at least said particular station that a collision occurred.

36. The circuit of claim 34 further comprising:

an upstream synchronizer for causing said transmitter to transmit on said downstream channel a bitstream containing an indication of the occurrence of a group of available slots in said upstream control channel.

37. The circuit of claim 34 further comprising:

a resource allocator for responding to said reservation request bitstream and an absence of available slots in said upstream payload channel, by causing said transmitter to transmit a bitstream on said downstream channel containing an acknowledgment of receipt of said reservation request bitstream from said particular station but also indicating that no slots of said upstream payload channel are currently available for allocation.

38. The circuit of claim 34 further comprising:

a downstream transmit data buffer for storing a payload bitstream received by said second receiver from said upstream payload channel originating from a first station and destined to a second station, and

an upstream synchronizer for causing said transmitter to transmit said payload bitstream on said downstream channel.

39. A method for enabling a station to communicate via a shared medium of a multiple access network comprising the steps of:

(a) transmitting a reservation request bitstream containing a request to reserve one or more slots of an upstream payload channel on an upstream control channel,

(b) receiving a plurality of bitstreams from a downstream channel, including at least one bitstream containing an indication of one or more slots of said upstream payload channel assigned to said station for transmitting bitstreams,

(c) transmitting payload bitstreams on said payload channel, only at said assigned slots of said upstream payload channel, and

(d) switching between transmitting said reservation request bitstreams and the payload bitstreams, such that said reservation request and payload bitstreams are sequentially transmitted.

40. The method of claim 39 further comprising the steps of:

(e) after beginning to perform step (a), receiving from said downstream channel a bitstream indicating that a collision occurred in said upstream control channel in performing said step (a), and

(f) in response, retransmitting said reservation request bitstream.

41. The method of claim 39 further comprising the steps of:

(e) prior to step (a), waiting until a bitstream is received from said downstream channel indicating the identity of an available group of one or more reservation slots in said upstream control channel, and

(f) if data is available for transmission from said station, randomly determining, based on said indicated available group of reservation slots , whether or not to perform step (a), but only during one of said reservation slots of said indicated group of reservation slots.

42. The method of claim 39 further comprising the steps of:

(e) after performing step (a) but before step (b), setting an acknowledgment timer, and

(f) in response to said acknowledgment timer expiring before receiving a bitstream containing an acknowledgment from said downstream channel, repeating step (a).

43. The method of claim 42 further comprising the steps of:

(g) after performing step (d), but before performing step (f), receiving a bitstream from said downstream channel containing an acknowledgment of receipt of said reservation request but also indicating that no slots in said upstream payload channel are available for allocation, and

(h) refraining from repeating step (a) in said step (f).

44. The method of claim 39 further comprising the step of:

(e) receiving from said downstream channel a payload bitstream containing a communicated message originating from another station in said multiple access network.

45. The method of claim 39 wherein each of said bitstreams received from said downstream channel are organized into MPEG-2 transport packets.

46. The method of claim 39 wherein said upstream control channel, said upstream payload channel and said downstream channel each have a mutually different frequency band.

47. The method of claim 39 wherein said multiple access network is a cable network, said station is a subscriber station and said shared medium includes cabling.

48. The method of claim 39 wherein said multiple access network is a wireless network, said station is a communication unit and said shared medium is the air.

49. The method of claim 39 wherein said multiple access network is a satellite network, said station is an earth station and said shared medium comprises the air and space.

50. The method of claim 39 wherein said downstream channel is received by a plurality of stations via said shared medium.

51. The method of claim 39 wherein said upstream control channel and said upstream payload channel are multiple access channels.

52. The method of claim 39 wherein first and second modulation techniques are used for said upstream control channel and said upstream payload channel, respectively, said first modulation technique optimizing the robustness of said upstream control channel without degrading the robustness or utilization of said upstream payload channel.

53. The method of claim 39 wherein in step (a), said upstream control channel on which said bitstream containing said request is transmitted is one of plural upstream control channels.

54. The method of claim 39 wherein in step (b), said downstream channel on which said bitstream containing said indication is received is one of plural downstream channels.

55. The method of claim 39 wherein in step (c), said upstream payload channel on which said bitstream is transmitted is one of plural upstream payload channels.

56. The method of claim 39 wherein prior to step (a), further comprising the step receiving

a bitstream indicating an identity of said multiple access network from said downstream channel, wherein said identity of said network includes at least an identity of said downstream and upstream channels.

57. In a central controller of a multiple access network, a method for enabling communication of bitstreams from a station via a shared medium of the network comprising the steps of:

(a) receiving from an upstream control channel, a reservation request bitstream, requesting reservation of slots for a particular station,

(b) transmitting on a downstream channel, a bitstream indicating one or more slots assigned to said particular station, and

(c) receiving a bitstream from one or more of said assign slots of an upstream payload channel,

wherein the received reservation request and payload bitstreams are transmitted from each said station by switching between said upstream control and upstream payload channels.

58. The method of claim 57 further comprising the steps of:

(d) detecting a collision during said step (a), and

(e) in response to said collision, transmitting a bitstream in said download channel including a notification to each station that a collision

occurred at a particular reservation request slot as indicated by at least one of a network identifier, an upstream control channel identifier and a reservation request mini-slot identifier.

59. The method of claim 57 further comprising the steps of:

(d) transmitting on said downstream channel a bitstream including an indication of the occurrence of a group of one or more available slots on said upstream control channel.

60. The method of claim 57 further comprising the steps of:

(d) after step (a) but before step (b), in response to an absence of available slots in said upstream payload channel, transmitting a bitstream on said downstream channel including an acknowledgment of receipt of said reservation request from said particular station but also including an indication that no slots of said upstream payload channel are currently available for allocation.

61. The method of claim 57 further comprising the steps of:

(d) receiving a payload bitstream from said upstream payload channel originating from a first station and destined to a second station, and

(e) transmitting said payload bitstream on said downstream channel.

62. The method of claim 57 wherein said upstream control channel, said upstream payload channel and said downstream channel each have a mutually different frequency band.

63. The method of claim 57 wherein said upstream control channel and said upstream payload channel are multiple access channels.

64. The method of claim 57 wherein said downstream channel is received by a plurality of stations via said shared medium.

65. The method of claim 57 wherein in step (b), each of the assigned slots being indicated by at least one of a network identifier, a station identifier, an upstream payload channel identifier and a mini-slot identifier.

66. The method of claim 59 wherein in step (d), each of said available slots being indicated by at least one of a network identifier, a station identifier, an upstream control channel identifier and a mini-slot identifier.

67. A method for communicating in a multiple access network comprising a central controller, a station and a shared medium for carrying signals between said central controller and said station, comprising the steps of:

(a) switching between transmitting payload bitstreams from a station to the central controller on an upstream payload channel and reservation request bitstreams from the station to the central controller

requesting reservation of one or more time slots in said upstream payload channel on an upstream control channel, and

(b) transmitting bitstreams from the central controller to the station indicating which slots of said upstream payload channel are assigned thereto a downstream channel.

68. A circuit for enabling a station to communicate via a shared medium of a multiple access network comprising:

(a) a receiver for receiving a plurality of bitstreams from a downstream channel, including at least one bitstream containing an indication of one or more slots of an upstream payload channel assigned to said station for transmitting bitstreams,

(b) a transmitter for transmitting payload bitstreams on said payload channel, only at said assigned slots of said upstream payload channel, and reservation request bitstreams containing a request to reserve one or more slots of an upstream payload channel on an upstream control channel, and

(c) a first switch for coupling said transmitter to one of said payload bitstream and said reservation request bitstream, based on an upstream channel selection.

69. The circuit of claim 68 further comprising a second switch for coupling a payload carrier frequency selection signal to said transmitter when said first switch couples said upstream payload channel to said transmitter,

and for coupling a control carrier frequency selection signal to said transmitter when said first switch couples said upstream control channel to said transmitter.

70. The circuit of claim 68 further comprising:

a retransmission rule decision circuit for responding to said receiver receiving from said downstream channel a bitstream containing an indication that a collision occurred in said upstream control channel by causing said first transmitter to transmit said reservation request bitstream onto said upstream control channel again.

71. The circuit of claim 68 further comprising:

a transmit scheduler for waiting until said receiver receives a bitstream from said downstream channel indicating the identity of an available group of one or more reservation slots in said upstream control channel, and if data is available for transmission from said station, randomly determining, based on said indicated available group of reservation slots, whether or not to cause said first transmitter to transmit said reservation request bitstream on said upstream control channel, but only during one of said reservation slots of said indicated group of reservation slots.

72. The circuit of claim 68 further comprising:

retransmission rule decision circuit for setting an acknowledgment timer, after said first transmitter transmits said reservation

request bitstream on said upstream control channel and, in response to said acknowledgment timer expiring before said receiver receives an bitstream containing an acknowledgment from said downstream channel, causing said first transmitter to transmit said reservation request bitstream on said upstream control channel again.

73. The circuit of claim 72 wherein after setting said timer, but before said timer expires, said receiver receives a bitstream from said downstream channel containing an acknowledgment of receipt of said reservation request bitstream but also containing an indication that no slots in said upstream payload channel are available for allocation, and wherein, in response, said retransmission rule decision circuit refrains from causing said first transmitter to transmit said reservation request bitstream on said upstream control channel again.

74. The circuit of claim 68 wherein said receiver receives from said downstream channel a payload bitstream containing a communicated message originating from another station in said network.

75. The circuit of claim 68 wherein a bitstream indicating an identity of said multiple access network is transmitted on said downstream channel, wherein said identity of said network includes at least an identity of said downstream and upstream channels.

76. The circuit of claim 68 wherein a bitstream indicating an identity of each of the assigned upstream payload slots is transmitted on said downstream channel, said bitstream indicating said identity based on at least one of a network identifier, a station identifier, an upstream payload channel identifier and a mini-slot identifier.

77. The circuit of claim 68 wherein a bitstream indicating an identity of assigned upstream reservation request slots is transmitted on said downstream channel, said bitstream indicating said identity based on at least one of a network identifier, a station identifier, an upstream control channel identifier and a mini-slot identifier.

78. The circuit of claim 77 wherein a bitstream indicating a notification to each station that a collision occurred at a particular reservation request slot is transmitted on said downstream channel, said bitstream indicating said notification based on at least one of said network identifier, said station identifier, said upstream control channel identifier and said mini-slot identifier.

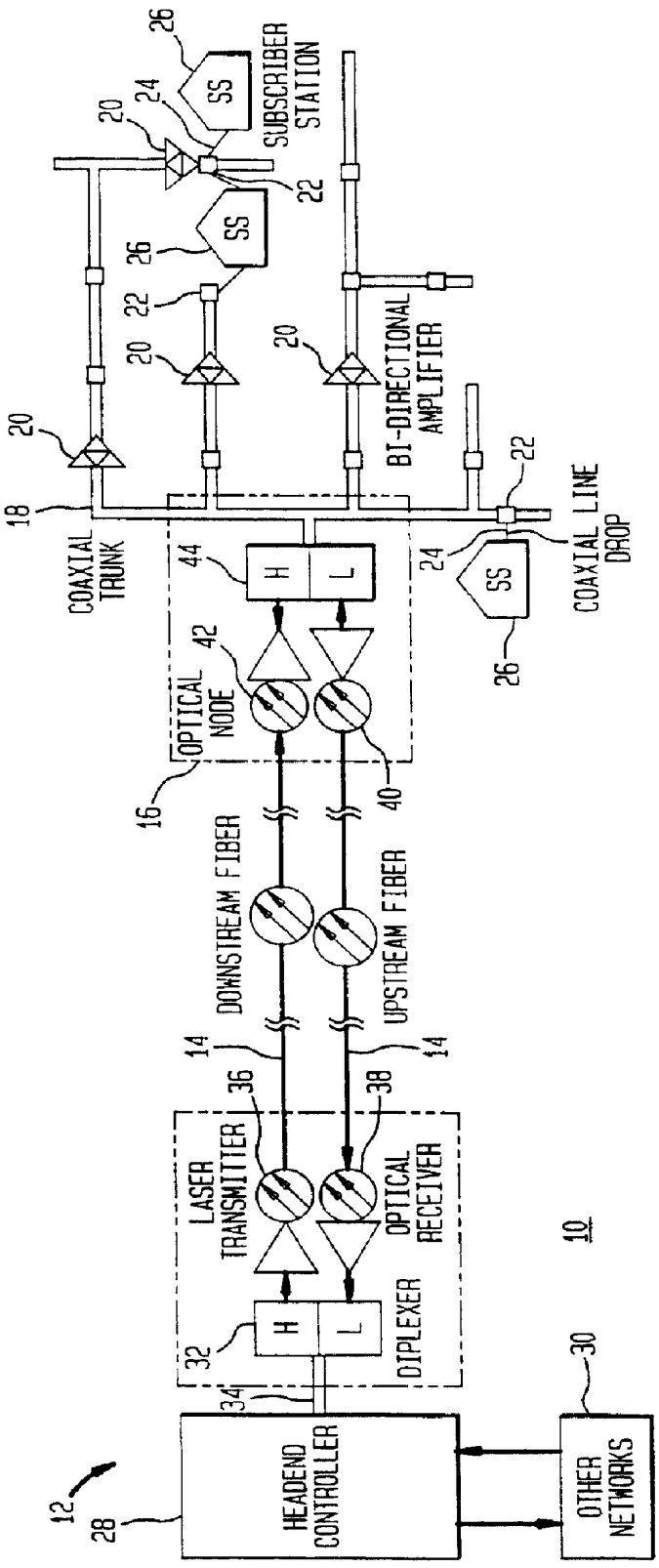



FIG. 1
(PRIOR ART)

FIG. 2
(PRIOR ART)

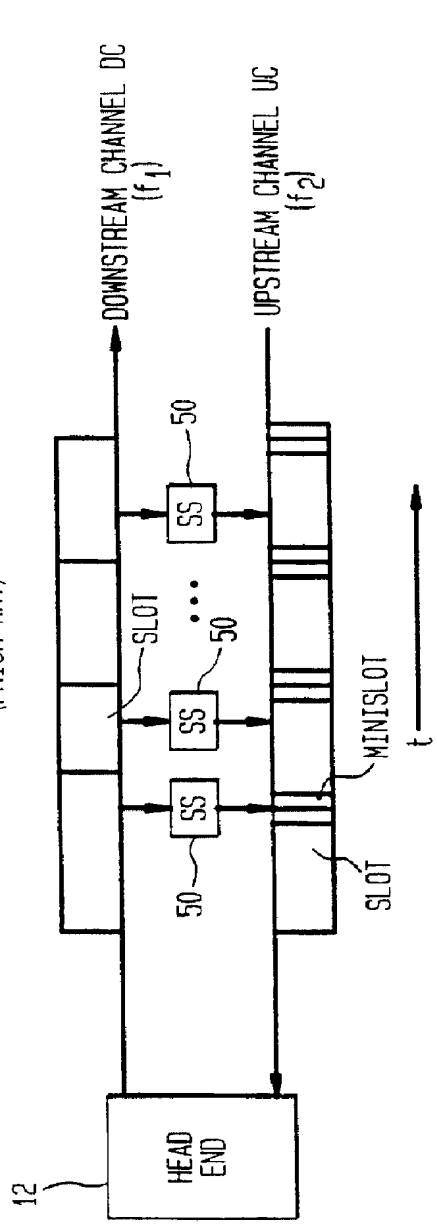



FIG. 3
(PRIOR ART)

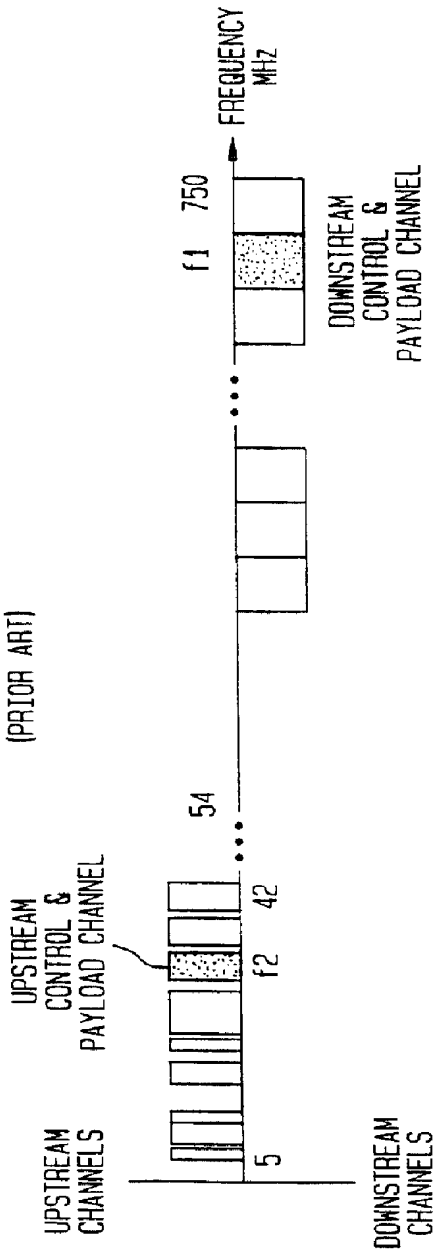


FIG. 4
(PRIOR ART)

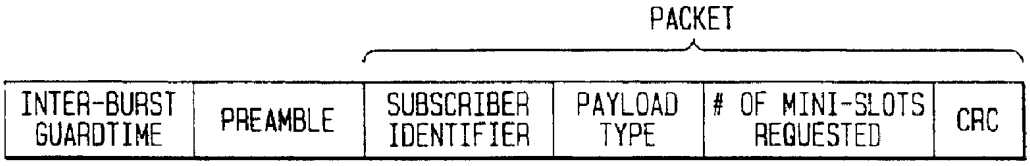



FIG. 5
(PRIOR ART)

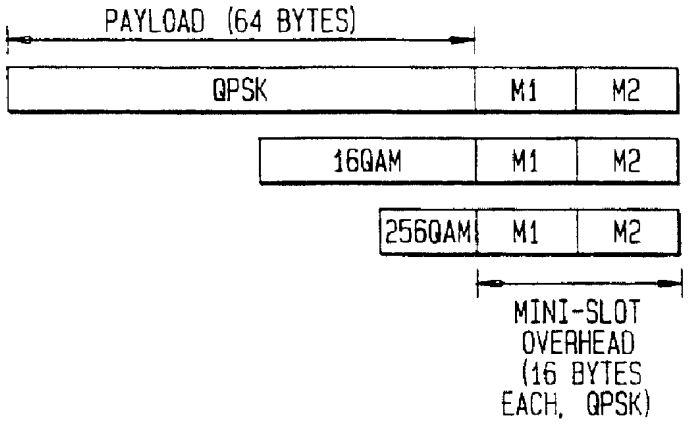
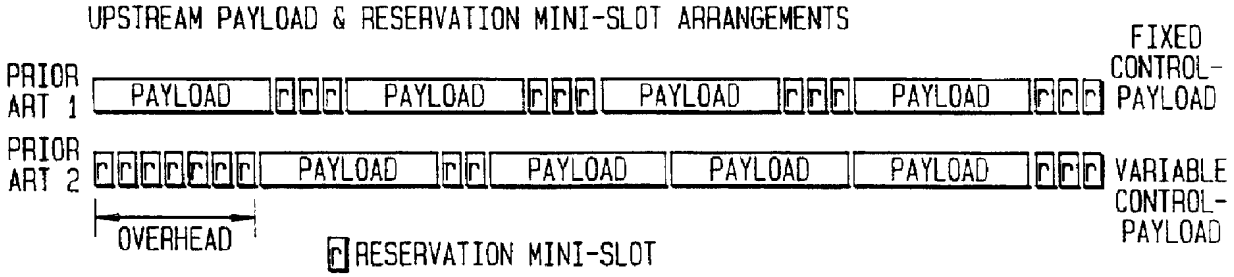



FIG. 6
(PRIOR ART)



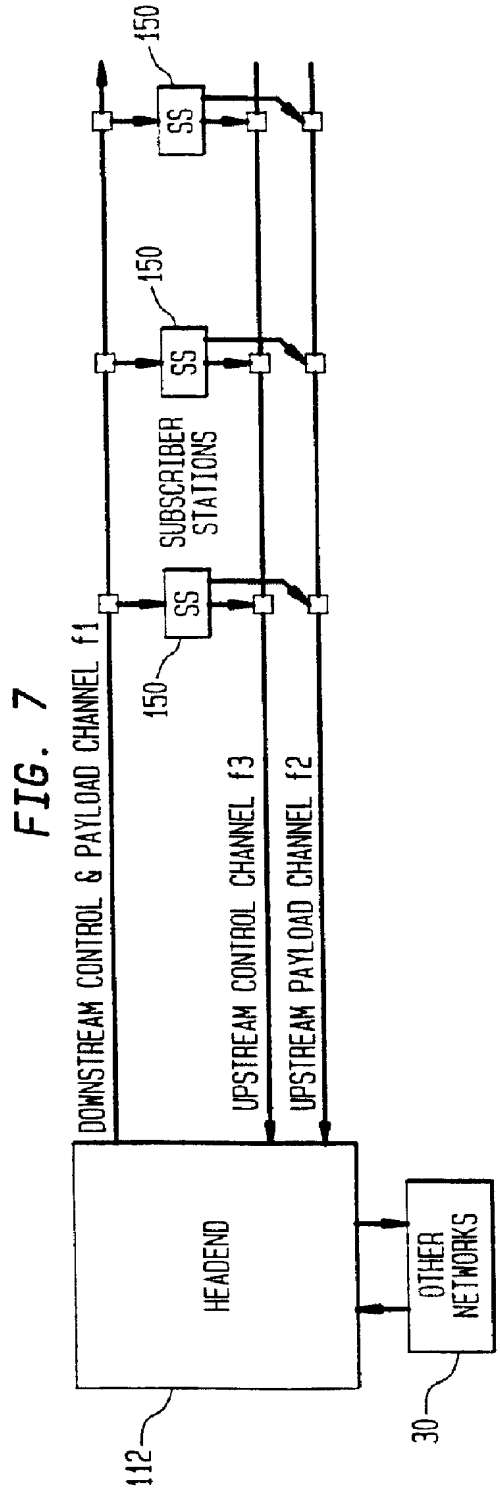



FIG. 7

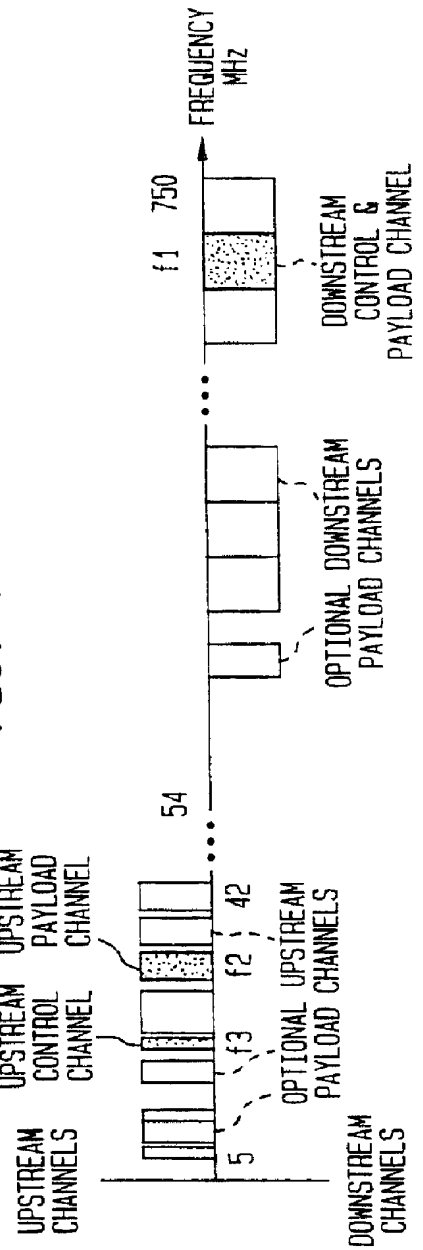



FIG. 8

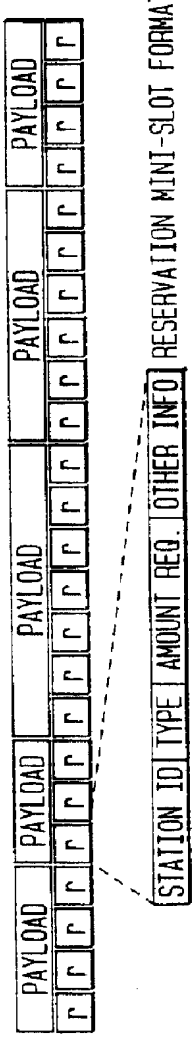



FIG. 9

FIG. 10A

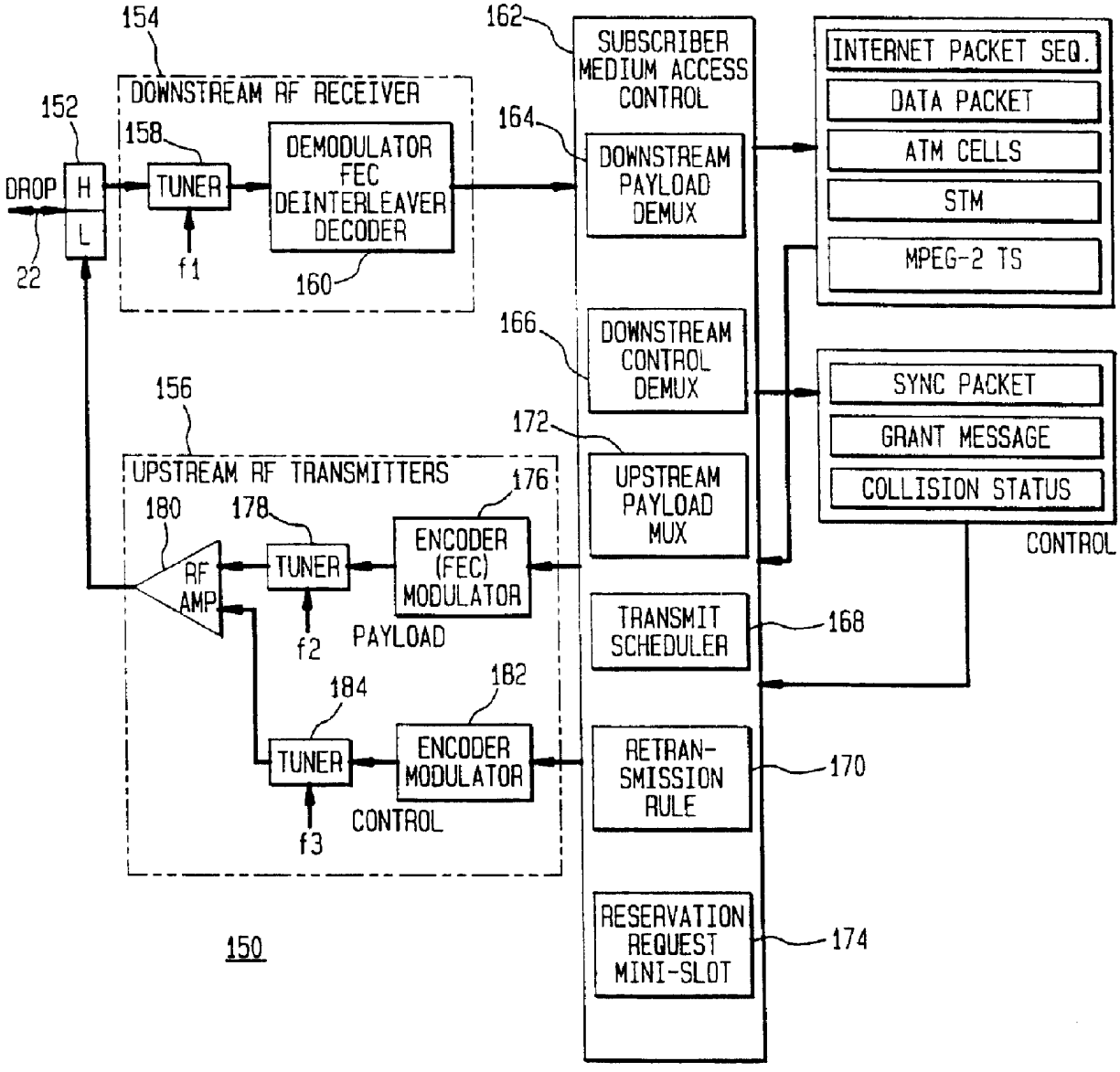

154
DOWNSTREAM RF RECEIVER
152
158
DROP
H
L
TUNER
f1
DEMODULATOR FEC DEINTERLEAVER DECODER
160
22
162
SUBSCRIBER MEDIUM ACCESS CONTROL
164
DOWNSTREAM PAYLOAD DEMUX
INTERNET PACKET SEQ.
DATA PACKET
ATM CELLS
STM
MPEG-2 TS
166
DOWNSTREAM CONTROL DEMUX
SYNC PACKET
GRANT MESSAGE
COLLISION STATUS
CONTROL
156
UPSTREAM RF TRANSMITTERS
172
UPSTREAM PAYLOAD MUX
176
180
178
RF AMP
TUNER
ENCODER (FEC) MODULATOR
f2
PAYLOAD
TRANSMIT SCHEDULER
168
184
182
TUNER
ENCODER MODULATOR
RETRAN-SMISSION RULE
170
f3
CONTROL
RESERVATION REQUEST MINI-SLOT
174
150

FIG. 10B

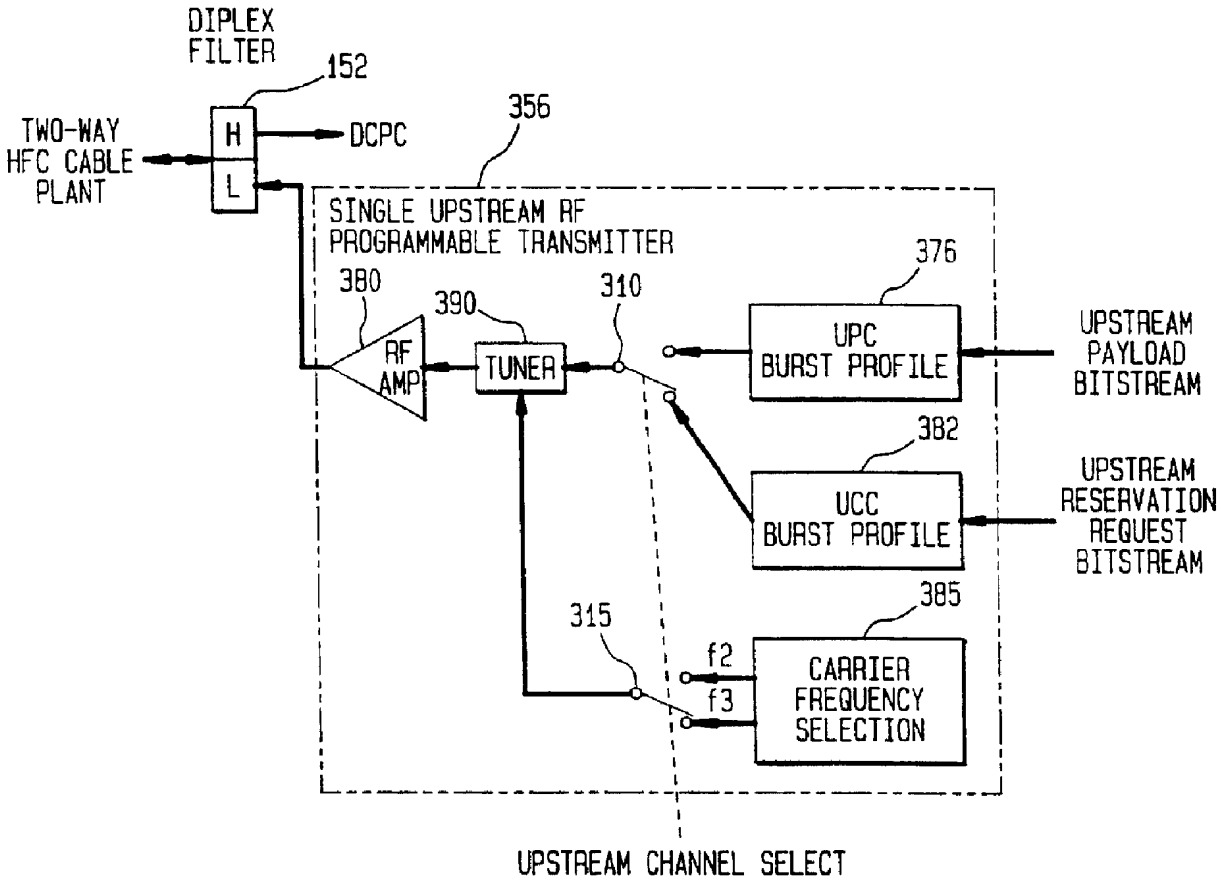

DIPLEX FILTER
152
TWO-WAY HFC CABLE PLANT
H
L
DCPC
356
SINGLE UPSTREAM RF PROGRAMMABLE TRANSMITTER
380
390
310
376
RF AMP
TUNER
UPC BURST PROFILE
UPSTREAM PAYLOAD BITSTREAM
382
UCC BURST PROFILE
UPSTREAM RESERVATION REQUEST BITSTREAM
315
385
f2
f3
CARRIER FREQUENCY SELECTION
UPSTREAM CHANNEL SELECT

FIG. 11

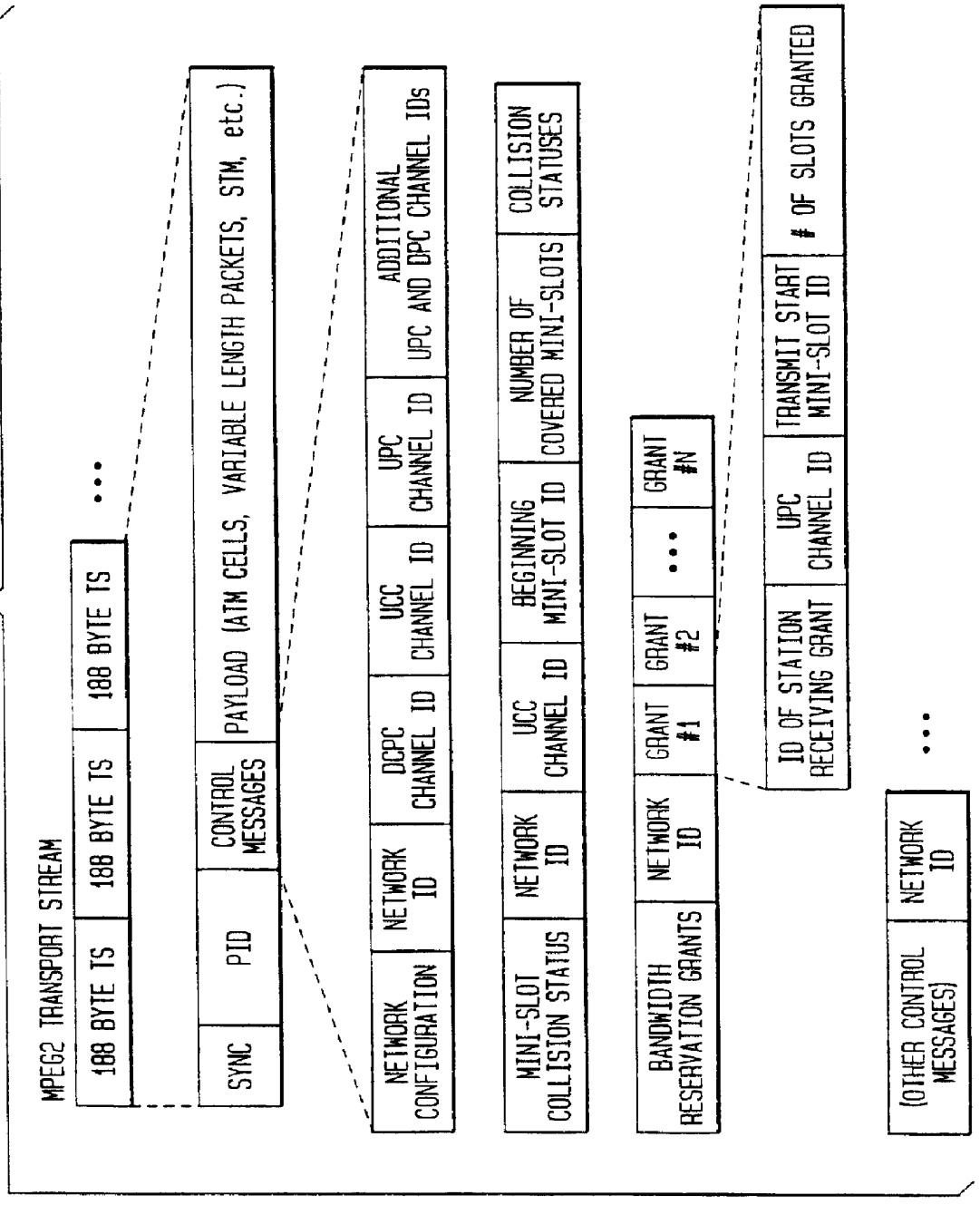

MPEG2 TRANSPORT STREAM
188 BYTE TS
188 BYTE TS
188 BYTE TS
...
SYNC
PID
CONTROL MESSAGES
PAYLOAD (ATM CELLS, VARIABLE LENGTH PACKETS, STM, etc.)
NETWORK CONFIGURATION
NETWORK ID
DCPC CHANNEL ID
UCC CHANNEL ID
UPC CHANNEL ID
ADDITIONAL UPC AND DPC CHANNEL IDs
MINI-SLOT COLLISION STATUS
NETWORK ID
UCC CHANNEL ID
BEGINNING MINI-SLOT ID
NUMBER OF COVERED MINI-SLOTS
COLLISION STATUSES
BANDWIDTH RESERVATION GRANTS
NETWORK ID
GRANT #1
GRANT #2
...
GRANT #N
ID OF STATION RECEIVING GRANT
UPC CHANNEL ID
TRANSMIT START MINI-SLOT ID
# OF SLOTS GRANTED
(OTHER CONTROL MESSAGES)
NETWORK ID
...

FIG. 12

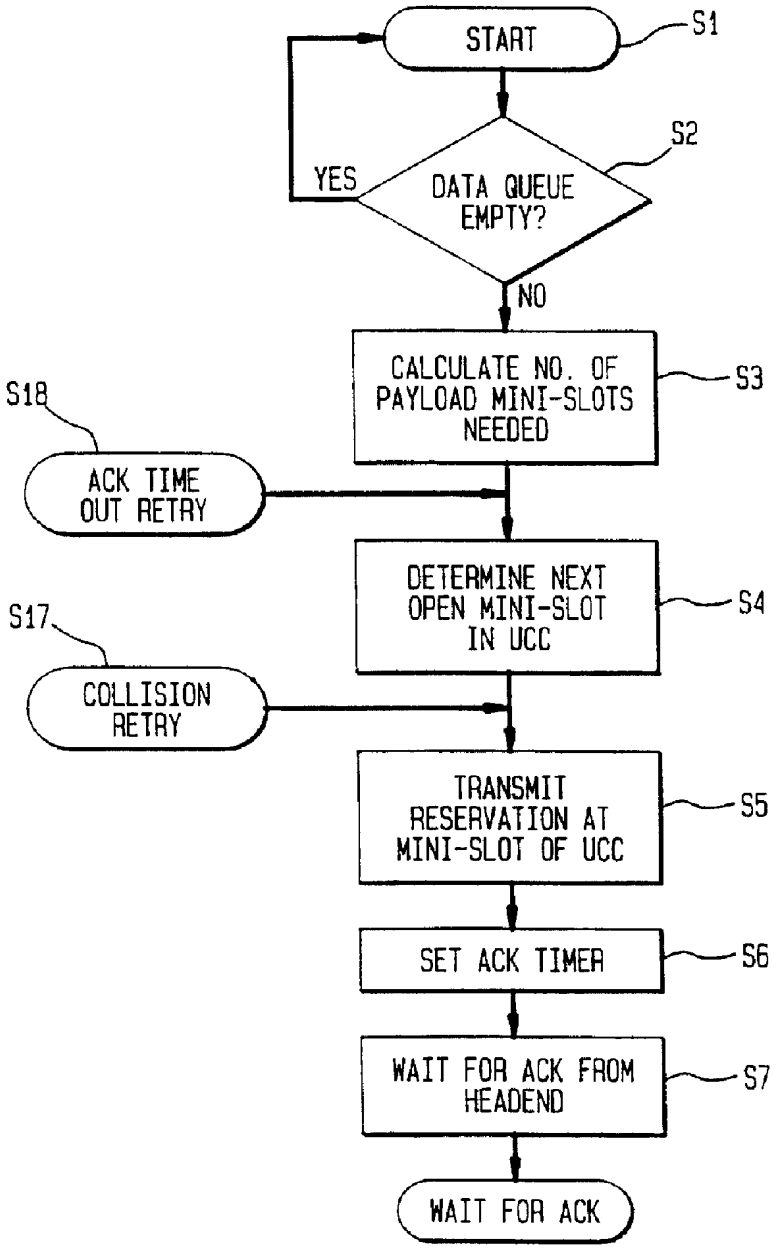

START
S1
S2
YES
DATA QUEUE EMPTY?
NO
CALCULATE NO. OF PAYLOAD MINI-SLOTS NEEDED
S3
S18
ACK TIME OUT RETRY
DETERMINE NEXT OPEN MINI-SLOT IN UCC
S4
S17
COLLISION RETRY
TRANSMIT RESERVATION AT MINI-SLOT OF UCC
S5
SET ACK TIMER
S6
WAIT FOR ACK FROM HEADEND
S7
WAIT FOR ACK

FIG. 13

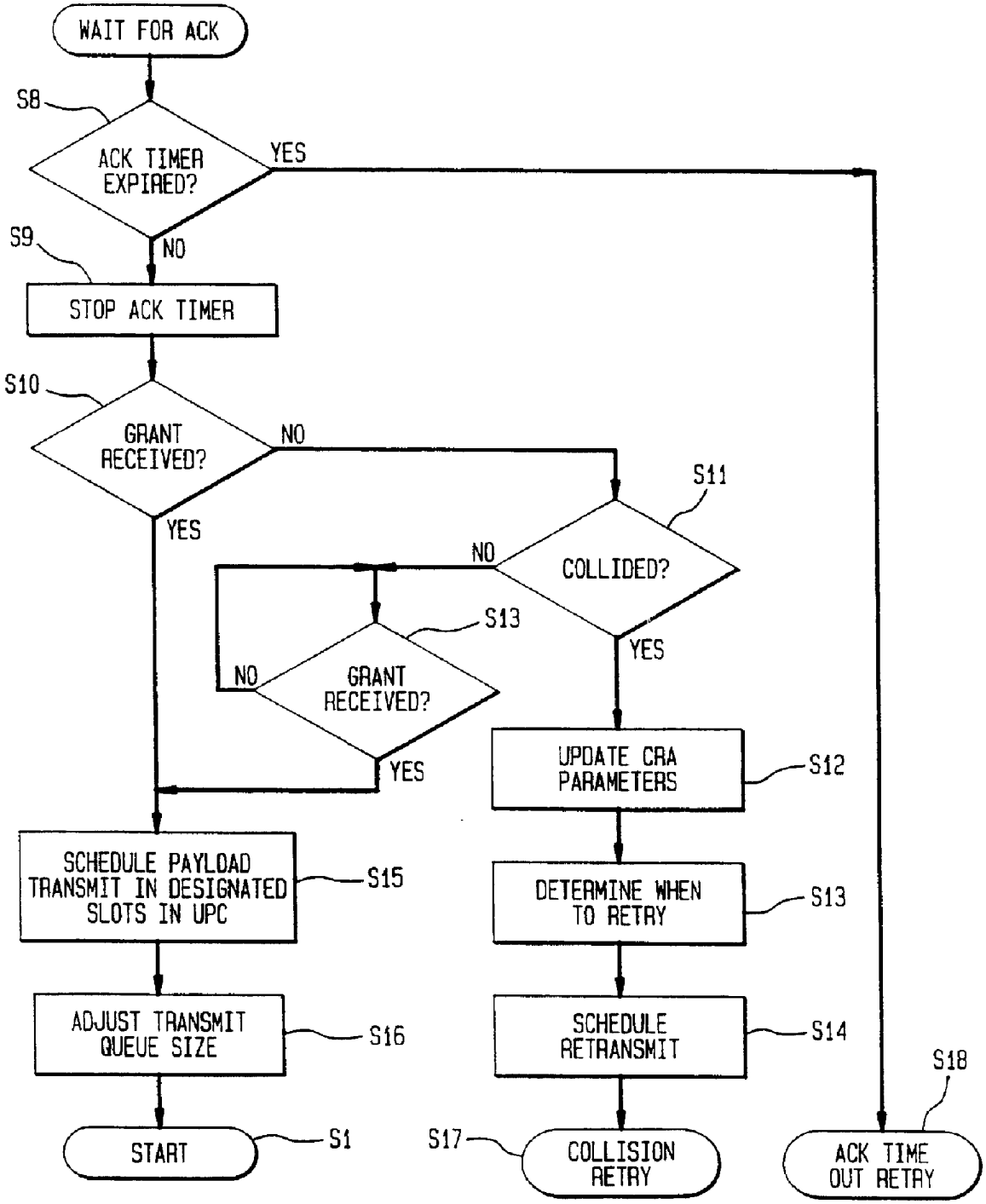
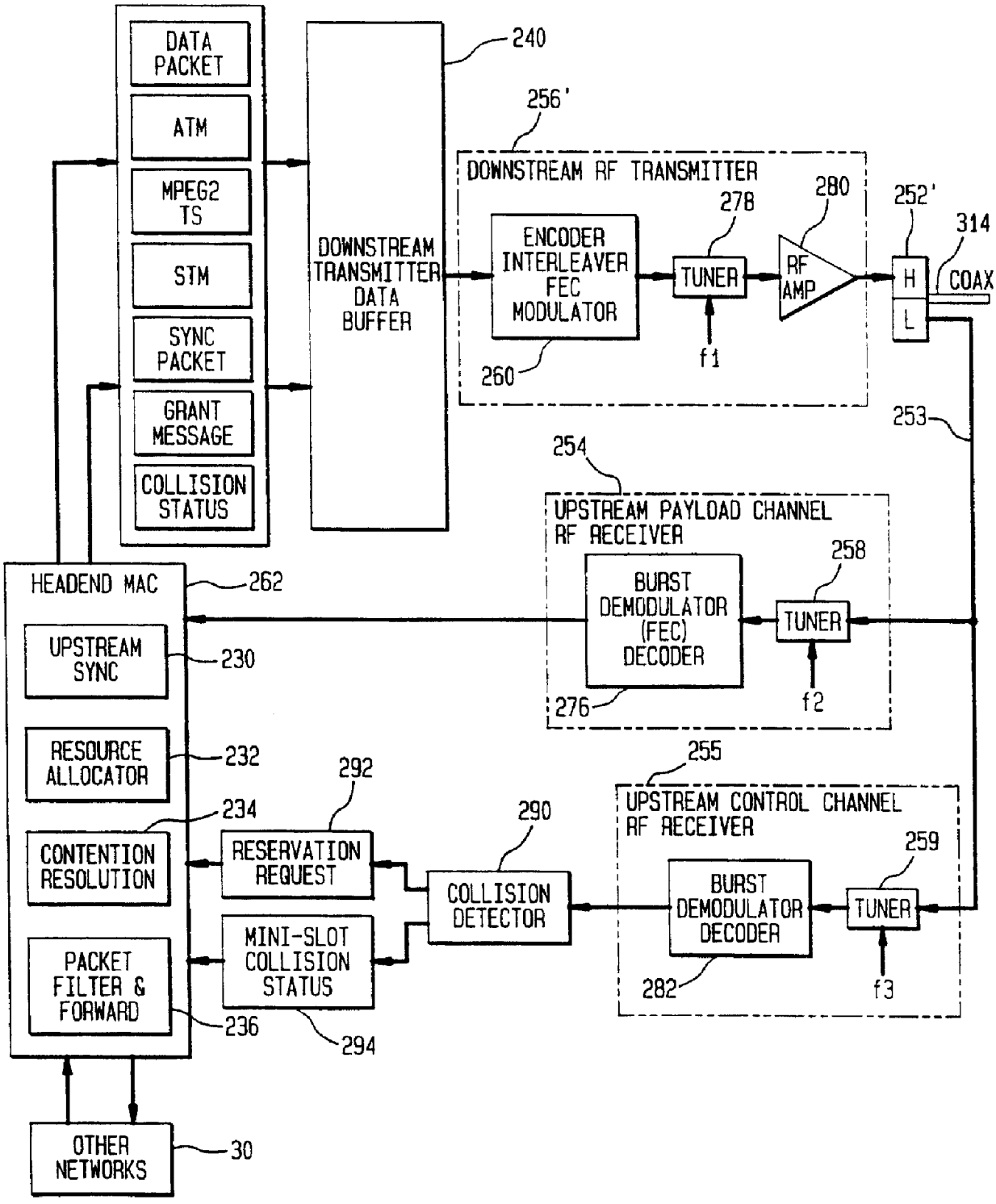

WAIT FOR ACK
S8
ACK TIMER EXPIRED?
YES
NO
S9
STOP ACK TIMER
S10
GRANT RECEIVED?
NO
YES
S11
COLLIDED?
NO
YES
S13
GRANT RECEIVED?
NO
YES
UPDATE CRA PARAMETERS
S12
DETERMINE WHEN TO RETRY
S13
SCHEDULE RETRANSMIT
S14
SCHEDULE PAYLOAD TRANSMIT IN DESIGNATED SLOTS IN UPC
S15
ADJUST TRANSMIT QUEUE SIZE
S16
START
S1
S17
COLLISION RETRY
S18
ACK TIME OUT RETRY

FIG. 14


DATA PACKET
ATM
MPEG2 TS
STM
SYNC PACKET
GRANT MESSAGE
COLLISION STATUS
240
DOWNSTREAM TRANSMITTER DATA BUFFER
256'
DOWNSTREAM RF TRANSMITTER
ENCODER INTERLEAVER FEC MODULATOR
260
278
TUNER
f1
280
RF AMP
252'
H
L
314
COAX
253
254
UPSTREAM PAYLOAD CHANNEL RF RECEIVER
BURST DEMODULATOR (FEC) DECODER
276
258
TUNER
f2
HEADEND MAC
262
UPSTREAM SYNC
230
RESOURCE ALLOCATOR
232
CONTENTION RESOLUTION
234
PACKET FILTER & FORWARD
236
292
RESERVATION REQUEST
MINI-SLOT COLLISION STATUS
294
290
COLLISION DETECTOR
255
UPSTREAM CONTROL CHANNEL RF RECEIVER
BURST DEMODULATOR DECODER
282
259
TUNER
f3
OTHER NETWORKS
30

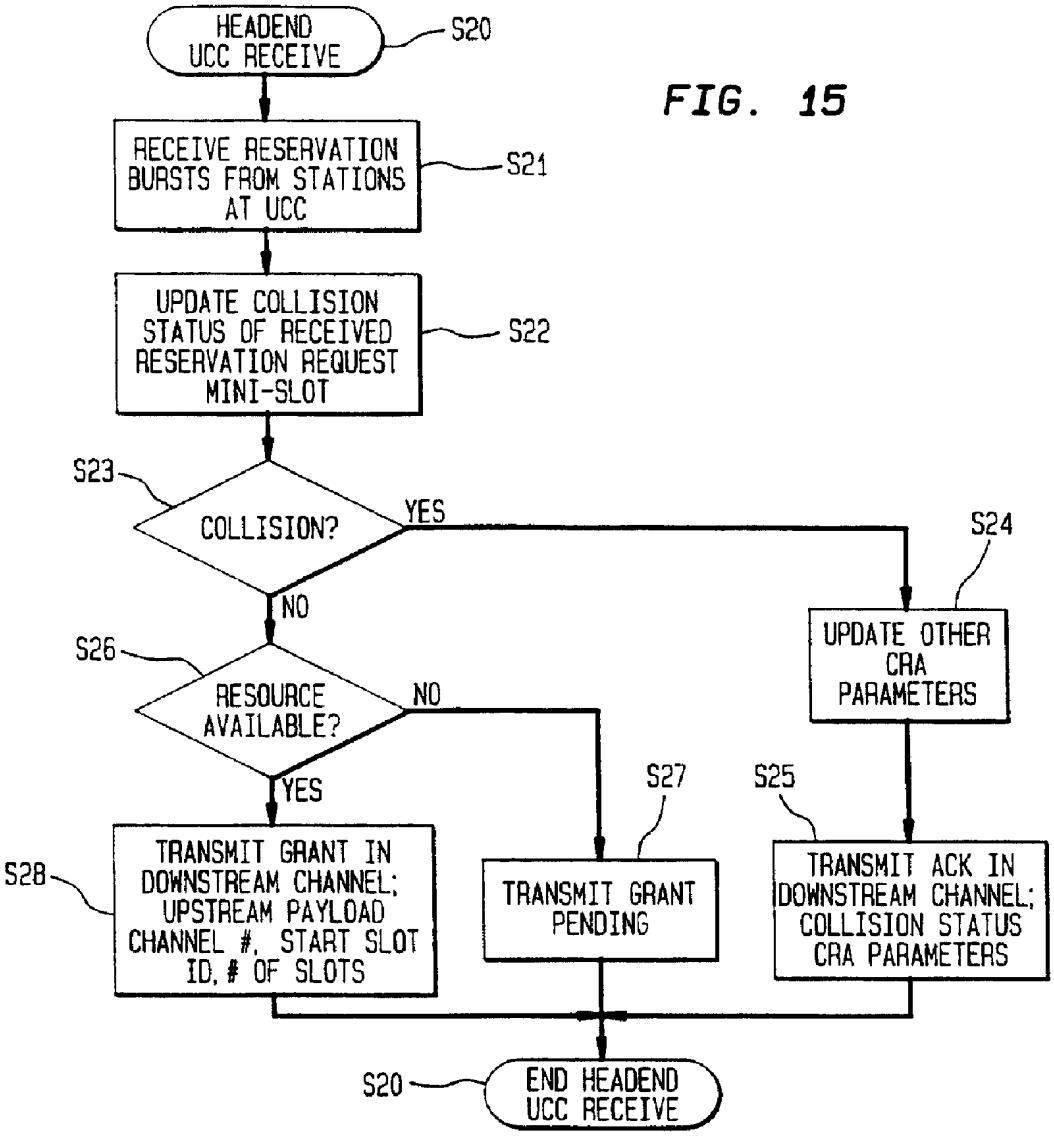
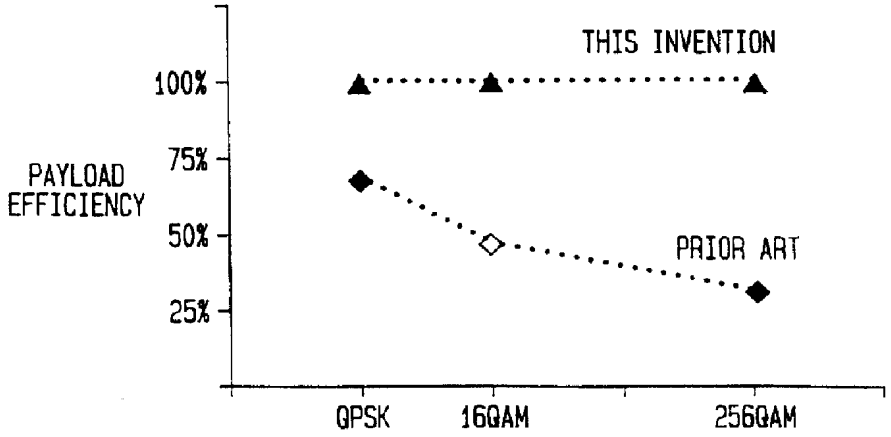

HEADEND UCC RECEIVE
S20
RECEIVE RESERVATION BURSTS FROM STATIONS AT UCC
S21
UPDATE COLLISION STATUS OF RECEIVED RESERVATION REQUEST MINI-SLOT
S22
S23
COLLISION?
YES
S24
NO
UPDATE OTHER CRA PARAMETERS
S26
RESOURCE AVAILABLE?
NO
YES
S27
S25
S28
TRANSMIT GRANT IN DOWNSTREAM CHANNEL; UPSTREAM PAYLOAD CHANNEL #, START SLOT ID, # OF SLOTS
TRANSMIT GRANT PENDING
TRANSMIT ACK IN DOWNSTREAM CHANNEL; COLLISION STATUS CRA PARAMETERS
S20
END HEADEND UCC RECEIVE

FIG. 15

FIG. 16


THIS INVENTION
100%
75%
50%
25%
PAYLOAD EFFICIENCY
PRIOR ART
QPSK
16QAM
256QAM